Biosurveillance with the smokey winged beetle bandit wasp: understanding buprestid populations and volunteer outcomes in Minnesota

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Thesis Abstract

Buprestid beetles can be difficult to sample due to their cryptic nature: larvae are usually wood-boring and feed under bark or within stems, and adults exhibit maturation feeding within tree canopies. There is no long-range sex pheromone identified for this family that could be exploited for sampling. In addition, currently available traps are only intermittently successful at detecting species of interest, including the invasive emerald ash borer, *Agrilus planipennis* Fairmaire, when at low densities. One method used to sample emerald ash borer and other buprestids is biosurveillance with a native ground-nesting hunting wasp, *Cerceris fumipennis* Say (Hymenoptera: Crabronidae). *Cerceris fumipennis* hunts for a wide range of buprestids, does not sting humans, and tends to nest at easily accessible human-disturbed sites such as baseball diamonds, making it easy for non-specialists to monitor nests and collect beetles in their communities. This work utilizes *C. fumipennis*-collected beetles along with existing museum records to create a checklist of buprestid species in Minnesota, investigates site-level variables that may influence the number and diversity of beetles collected by *C. fumipennis*, and elucidates individual outcomes for citizen science volunteers who monitor nesting aggregations of *C. fumipennis*.

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Thesis Introduction

Buprestids (Coleoptera) are one of the most diverse families in an immensely diverse order (Nicolay and Weiss 1918). While most play a positive ecological role by breaking down dead and dying wood (Grove 2002; New 2007), some can be pests under certain conditions. The two-lined chestnut borer *Agrilus bilineatus* Weber, for example, typically attacks oaks (*Quercus* spp.) stressed due to drought or other factors (Bright 1987; Solomon 1995). The most famous buprestid may be the emerald ash borer (EAB), *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae). EAB is a wood-boring forest insect pest introduced to North America from Asia around the early 1990s, although it was not detected until 2002 (Siegert et al. 2007). EAB is considered an invasive pest due to its ability to attack and kill almost every species of native North American ash (*Fraxinus*) species (Cappaert et al. 2005; Poland and McCullough 2006; Herms and McCullough 2014). In North America, EAB larvae tunnel under the bark of ash trees and feed in the phloem throughout the summer, depriving trees of nutrients and effectively girdling trees at high densities (Anulewicz et al. 2007). Mortality from EAB has resulted in economic, environmental, aesthetic, and cultural losses due to the almost complete extirpation of ash in the urban and forested environments where EAB has been introduced and spread.

As EAB continues to spread across North America, one of the first challenges facing communities is efficient detection to determine when and where to begin management strategies and associated outreach. Management for EAB consists of quarantines, educational campaigns to prevent humans from facilitating its spread in firewood, chemical controls injected directly into trees, a classical biocontrol program, and proactive removal of dying or woodpecked ash, especially in urban settings (Herms and McCullough 2014; USDA-APHIS 2015; Fahrner et al. 2017). However, detecting buprestid beetles on the landscape can be challenging, as the larval stage feeds under the bark and adults are not known to use long-range sex pheromones (Bartelt et al. 2007; Herms and McCullough 2014).

Managers commonly use purple prism sticky traps to detect EAB. Traps are baited with (*Z*)-3-hexanol, a green-leaf volatile released by stressed ash trees that is attractive to EAB. However, these traps are not always effective at low beetle densities (Crook and Mastro 2010; Marshall et al. 2010; USDA-APHIS 2018). Purple prism traps can also be used to survey buprestid species other than EAB (Skvarla and Holland 2011). Buprestids, especially those in the genus *Agrilus*, are attracted to the color purple and are often attracted to plant volatiles (Francese et al. 2008; Skvarla and Holland 2011). However, purple prism traps more commonly capture beetles of other families, and do not effectively capture larger bodied buprestids such as those in the genera *Buprestis* or *Dicerca* (Skvarla and Holland 2011; Looney et al. 2014; Nalepa et al. 2015). Few studies have examined factors influencing biodiversity and distribution of buprestid beetles compared to other beetle families, likely due to collection challenges unique to Buprestidae.

Another proposed method for buprestid collection is the use of the solitary native ground nesting hunting wasp *Cerceris fumipennis* Say (Hymenoptera: Crabronidae) (Careless et al. 2014). Female *C. fumipennis* wasps forage for, paralyze, and provision nests almost exclusively with beetles in the family Buprestidae, including EAB (Scullen 1965; Marshall et al. 2005). Like other wasps in the genus *Cerceris, C. fumipennis* is a mass provisioning species. Females sequester multiple prey in a nest cell, lay a single egg on the underside of the uppermost beetle, and then close off the completed cell (Scullen and Wold 1969; Kurczewski and Miller 1984). After hatching, the wasp larva consumes the provisioned beetles, which range in number depending on the size of the beetles and the sex of the larva (Evans 1971). Hook and Evans (1991) found that the number of beetles placed into an individual nesting cell ranged from 3 large *Dicerca* beetles to 51 much smaller *Agrilus* beetles.

Cerceris fumipennis has a range that extends throughout North America east of the Rocky Mountains into southern Canada, although it has also been found as far west as British Columbia, Canada (Scullen 1965; Kimoto et al. 2015a). While *C. fumipennis* undergoes a partial or full second generation in its southern range, throughout its northern range it is univoltine (Evans 1971; Johnson et al. 2015). Wasps can be found nesting in aggregations in locations with hard packed sandy soil, usually emerging from, utilizing, and competing for nests from the previous year. New nest excavation has been observed to be rare (Mueller et al. 1992).

Researchers have been collecting buprestids from nesting aggregations of *C. fumipennis* for several decades, usually in the context of observational studies detailing wasp biology (Evans 1971; Evans and Rubink 1978; Kurczewski and Miller 1984; Hook and Evans 1991). Marshall et al. (2005) proposed using *C. fumipennis* as a tool to track the spread of EAB, which has led to increased interest in utilizing the wasp more broadly as a buprestid biosurveillance tool throughout its range. “Biosurveillance” is defined as the use of the natural behavior of one species to locate another. It is relatively easy for non-specialists to collect beetles from nesting aggregations of *C. fumipennis*, as females are unable to sting humans, drop beetles mid-flight when intercepted, tend to nest in easily accessible sites such as baseball diamonds, and do not change their foraging rate in response to human disturbance (Careless et al. 2014).

This ease of collection has led to the creation of citizen science "Wasp Watchers" programs in states where the range of *C. fumipennis* overlaps with that of EAB, including Connecticut, Iowa, Maine, Massachusetts, New Hampshire, New York, North Carolina, Rhode Island, Vermont, and Minnesota, which is the location of this work (Rosenholm 2012, http://waspwatchers.umn.edu/). "Wasp Watchers" are trained to recognize wasp nests and collect beetles from *C. fumipennis* females, either by netting them directly or through the use of "Careless collars;" pieces of plastic with holes just smaller than the diameter of a nest entrance hole designed to impede returning wasps (Careless 2008). Collected beetles may then be sent to a specialist capable of determining species-level identifications, which can be challenging for buprestids as dissection of genitalia is sometimes required (Paiero et al. 2012). A volunteer monitoring a *C. fumipennis* nest was credited with the initial detection of EAB in Connecticut in 2012 (Rutledge et al. 2013).

In addition to the scientific value of buprestid beetles collected by citizen science volunteers, there is the added potential for positive individual outcomes for volunteers. Interest in citizen science has been steadily increasing since the 1990s. This increase can be attributed to technological advances that make it easier for anyone to participate in data collection, requirements from granting agencies to include outreach/educational components in projects, and a general call for the democratization of science (Irwin 2006; Davies 2008; Shirk et al. 2012; Bonney et al. 2016). Programs may be contributory, meaning volunteers collect data to be analyzed and disseminated by scientists;

collaborative, meaning volunteers are also involved with the design and analysis of the project; or they may be co-created, with scientists and the public working together at every stage of a project (Danielsen et al. 2009; Shirk et al. 2012)

The Wasp Watchers program in Minnesota can be classified as a contributory or consultative citizen science project, with volunteers collecting data to be later utilized by local decision makers (Conrad and Hilchey 2011). The most commonly investigated outcome for individuals involved in contributory projects is content knowledge gain, although there may be additional outcomes such as attitude change towards science, social learning, or increased confidence in addressing environmental problems (Shirk et al. 2012; Stepenuck and Green 2015). Confidence to address problems, also known as "self-efficacy," may be especially low when it comes to environmental issues such as those concerning invasive species, as the problems may seem overwhelming and impossible for individuals to address (Jordan et al. 2011). Programs like Wasp Watchers that encourage the public to take concrete action to manage invasive species may be particularly effective in encouraging environmental self-efficacy. However, whether Wasp Watchers volunteers experience an increase in factors such as self-efficacy is unknown.

My thesis utilizes Wasp Watchers volunteer-collected data alongside researcher collected-data to describe buprestid populations in Minnesota. Buprestids are a poorly studied group, and few studies have examined factors influencing their diversity and distribution. In chapter one, I compile a checklist of buprestids for Minnesota, USA based on both buprestids collected from nesting aggregations of *C. fumipennis* and existing collection records dating back to the late 1800s. A statewide buprestid checklist for Minnesota had not been compiled previously, and this checklist will facilitate future work on buprestid diversity and distribution. Moreover, it creates a record that can be used to characterize future change that may occur as a result of the invasion of EAB or other woodborers. In chapter two, I compare the species richness of buprestids found around different Minnesota nesting sites of *C. fumipennis* and examine associated site-level factors that may influence species richness such as number of surrounding trees. Additionally, I investigate whether the prey collected reflects surrounding urban canopy, which will help determine the suitability of *C. fumipennis* for biosurveillance and reveal bias it may introduce as a survey tool. In chapter three, I examine individual outcomes for Wasp Watchers volunteers based on existing theory. I administer a survey to known Wasp Watchers volunteers to investigate self-reported change in constructs such as interest in learning, advocacy, and self-efficacy, with the hypothesis that increased program participation will have a positive impact on these factors, and ultimately pro-environmental behavior.

Chapters 1 and 2 of this thesis were prepared for publication in peer-reviewed journals. All chapters are the combined results of multiple authors, so I will use a plural voice for the remainder of the thesis. Chapter 1 is being prepared for submission to *ZooKeys*. Chapter 2 is being prepared for submission to *Biodiversity and Conservation*. As each chapter is intended to exist as a stand-alone unit, a small degree of redundancy may exist between chapters to preserve their integrities.

Chapter 1

An annotated checklist of the metallic woodboring beetles (Coleoptera: Buprestidae) of Minnesota

Summary

The future impact of the invasive emerald ash borer (EAB) *Agrilus planipennis* (Coleoptera: Buprestidae) on native North American buprestids is unknown. To determine how the range and composition of native buprestid species will change over time, knowledge of historical buprestid species distributions is necessary. We utilized a biosurveillance sampling method, namely the use of the native ground-nesting hunting wasp *Cerceris fumipennis*, along with University of Minnesota Insect Collection (UMSP) records, to create a checklist for Buprestidae in Minnesota, USA. Additional literature records are included, along with information on known and novel host plants, collection method, and collection date range for each species. We examined 5,127 specimens with Minnesota localities, documenting 110 species. Of these, 41 new state records are noted, including 12 collected from *C. fumipennis* nesting sites between 2013 and 2018. The strengths and limitations of sampling buprestid populations with *C. fumipennis* biosurveillance are discussed.

Introduction

The invasive emerald ash borer (EAB), *Agrilus planipennis* Fairmaire, has killed millions of ash (*Fraxinus* spp.) trees since its detection in 2002 in North America (Herms and McCullough 2014). All species of native North American ash are susceptible to infestation and have almost guaranteed mortality in the absence of insecticidal treatment (Cappaert et al. 2005; Poland and McCullough 2006; Herms and McCullough 2014). While EAB-induced ash mortality is known to have a short-term negative impact on forest productivity (Flower et al. 2013), the reported impacts of EAB presence on other arthropod species have been difficult to generalize, with some species increasing and some decreasing in abundance following ash mortality. Most research to date has focused on the impact of increased coarse woody debris and canopy gaps on ground and litter-dwelling species (Ulyshen et al. 2011; Gandhi et al. 2014; Perry and Herms 2016). The effect that EAB will have on native North American buprestid populations is unknown, although sampling techniques developed for EAB may also provide an opportunity to record buprestid populations before and after EAB establishment in a given state or province (Carlton et al. 2018).

One such sampling method is the use of the ground nesting wasp *Cerceris fumipennis* Say (Hymenoptera: Crabronidae). *Cerceris fumipennis* hunts primarily for beetles in the family Buprestidae, including EAB. Due to its inability to sting humans, its accessible nesting sites in human-disturbed locations, and its relatively narrow host range, *C. fumipennis* has been exploited in many states as a biosurveillance tool for the detection of EAB (Marshall et al. 2005; Careless et al. 2014), often in the form of citizen science programs that mobilize volunteers. *Cerceris fumipennis* biosurveillance is credited with the detection of EAB in Connecticut (Rutledge et al. 2013). While the purpose of these programs is ostensibly to detect EAB, they have also collected many other buprestid species and resulted in many new buprestid state and provincial records (Hook and Evans 1991; Swink et al. 2013, 2014; Westcott and Thomas 2015). In 2015, the citizen science program "Wasp Watchers" was formed by the University of Minnesota in partnership with the Minnesota Department of Agriculture (MDA) to help locate new EAB infestations

EAB is currently found in 18 Minnesota counties (https://www.mda.state.mn.us/eab) and will likely continue to spread throughout the state, either through natural dispersal or human-mediated transport (Muirhead et al. 2006; Mercader et al. 2009; Siegert et al. 2014). Five years of sampling at *C. fumipennis* nesting sites by Wasp Watchers volunteers and researchers from the University of Minnesota have resulted in the collection of thousands of buprestid beetles. These beetles, in addition to historical records from the University of Minnesota Insect Collection, represent a unique opportunity to record buprestid populations before, after, and in the midst of EAB infestation in Minnesota. Collection specimens were cataloged and are listed here to expand known range for many buprestid species, update host information, and aid in future assessments of the impact of EAB on native buprestid species.

Materials and Methods

This checklist is based on specimens housed in the University of Minnesota Insect Collection (UMSP), including buprestids collected by Wasp Watcher volunteers and program facilitators during *C. fumipennis* colony monitoring from 2014 to 2018. The UMSP contains four million insect specimens from Minnesota and around the world, although this checklist is limited to previously identified buprestids with Minnesota localities. Specimens from *C. fumipennis* sampling were identified by M. Hallinen or W. Steffens using available keys and field guides (Fisher 1928; Barter and Brown 1949; Wellso et al. 1976; Hansen et al. 2011; Paiero et al. 2012), with uncertain identifications confirmed by Norman Woodley (USDA ARS Systematic Entomology Lab, Beltsville, MD), T.C MacRae (Monsanto Company, Chesterfield, MO), S.G. Wellso (Michigan State University, East Lansing, MI), and R.L. Westcott (Oregon Department of Agriculture, Salem, OR). Additional literature records are cited from Nelson et al. (2008), Hansen et al. (2011), and MacRae and Basham (2013). New state records are noted. Several species considered here as state records were previously reported on bugguide.net or cedarcreek.umn.edu as occurring in Minnesota. Previously, these records were considered incomplete as they did not include full locality information or species were identified from photographs alone, thus precluding confirmation of species identification. Buprestids collected from the Cedar Creek Ecosystem Science Reserve in Minnesota (45°24'07.2"N, 93°11'57.8"W) are included in this list. Species *Buprestis striata* Fabricius, *B. sulcicollis* LeConte, *Chrysobothris sexsignata* Say, *Phaenops aeneola* Melsheimer, and *P. drummondi drummondi* Kirby are state records recently published by Gandhi et al. (2009). We mention them here as they have been overlooked by subsequent guides, but are not relisted as records in this checklist.

Information from the label of each specimen was entered into a spreadsheet for upload to the UMSP "Specify" database. Attributes included collector, date, identifying authority, locality, hosts, and collection method, when available. We list county records, defined as the number of specimens examined in the collection (e.g. n=3), followed by a list of Minnesota counties where that species is recorded. Date range occurrences are given as the earliest and latest collection dates across all records for a given species. In addition to date range, Minnesota larval and adult host information and collecting methods are noted in this list, with host information reported from collection labels and from Nelson et al. (2008). Potential hosts were narrowed to species occurring in Minnesota using the U.S. Department of Agriculture Plants Database (plants.usda.gov/java/) and the Minnesota Department of Natural Resources' MNTaxa State of Minnesota Vascular Plant Checklist (https://webapps15.dnr.state.mn.us/mntaxa/reports/index). Previously unrecorded host plants are listed in bold font. Incomplete records (i.e., those missing exact date or locality information) and species that were recorded in Minnesota but that likely did not establish in the state are included in this list, along with comments where reservations might exist. New state records are recorded in the format of county, locality, date, collector, and collection method (if specified). When there was found to be more than one specimen of a species newly recorded in the state, the label information with the earliest collection date is included as the state record. All specimen data are available on request and all specimens are currently housed in the UMSP.

Results

Label records were examined for 7,224 adult Buprestidae. A total of 5,127 specimens and 110 species were recorded from Minnesota, with the additional 2,097 labels with non-Minnesota localities examined for additional information on host and collection method. Genera and species are listed alphabetically. A total of 41 new Minnesota state records are included, including 12 collected from *C. fumipennis* nesting sites. Most of the 29 state records for species collected by non-C. *fumipennis* sampling techniques consist of specimens that have been in the collection for many decades, but not yet recorded in North American buprestid catalogs. Maps displaying the number of beetles for a given species caught in each county and the time passed since last collection (within 20 years) are provided in the appendix (Appendix 1.1).

1. *Acmaeodera pulchella* (Herbst, 1801)

County records (*n* = 147): Anoka, Carlton, Chisago, Crow Wing, Dakota, Doulas, Faribault, Goodhue, Hennepin, Houston, Isanti, Kanabec, Le Sueur, Mille Lacs, Morrison, Nicollet, Olmsted, Otter Tail, Pope, Ramsey, Scott, Steele, Stevens, Wabasha, Washington, and Winona.
Collection dates: June 13 – September 12.
Minnesota hosts: Adults collected on "prairie flowers," including ***Achillea millefolium* L.**, *Coreopsis palmata* Nutt., ***Echinacea angustifolia* DC.**, and *Rudbeckia hirta* L. Larval hosts recorded as *Crataegus* spp. and *Gleditsia triacanthos* L., adults also recorded on *Acer saccharinum* L. and *Quercus alba* L.
Collection method: On prairie flowers, by Malaise trap, and as *C. fumipennis* prey.

2. *Actenodes acornis* (Say, 1833)

County records (*n* = 17): Anoka, Dakota, Goodhue, Hennepin, Olmsted, Ramsey, and Washington.
Collection dates: June 6 – August 4.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Acer rubrum* L., *A. saccharum* Marsh., *Betula nigra* L., *Carya ovata* (Mill.) K. Koch, *Fagus grandifolia* Ehrh., and *Quercus velutina* Lam. Adults also on *Q. prinoides* Willd.
Collection method: *C. fumipennis* prey.
New state record: Washington County, Tilsen Park, Oakdale, 44.999932 °N, -92.966689 °W, 22 July 2014, B. Kuehn., collected at *C. fumipennis* nesting site. Two undated MN specimens without county information; identified in 1922.

3. *Actenodes simi* Fisher, 1940

County records (*n* = 3): Chisago, Goodhue, and Washington.
Collection dates: July 17 – July 22.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Acer saccharinum* L. and *Quercus alba* L. Adults also on *Q. velutina* Lam.
Collection method: All specimens collected as *C. fumipennis* prey.
New state record: Goodhue County, First Covenant Church, Red Wing, 44.54266 °N, -92.546934 °W, 18 July 2015, C. Struss, collected at *C. fumipennis* nesting site.

4. *Agrilus acutipennis* Mannerheim, 1837

County records (*n* = 8): Cass, Clearwater, Morrison, Olmsted, and Otter Tail.
Collection dates: June 6 – July 26.
Minnesota hosts: Collected on *Corylus* sp. Larval host recorded as *Quercus alba* L. Adults also recorded on *Amelanchier arborea* (Michx. F.) Fern., *Betula* sp., *Carya cordiformis* (Wangenh.) K. Koch, *Corylus americana* Walt., *Juglans nigra* L., *Populus* sp., *Quercus macrocarpa* Michx., and *Q. velutina* Lam.
Collection method: Unspecified and sweeping *Corylus* sp.

5. *Agrilus anxius* Gory, 1841

County records (*n* = 175): Beltrami, Cass, Chisago, Clearwater, Cook, Crow Wing, Dakota, Goodhue, Hennepin, Houston, Isanti, Itasca, Kittson, Lake, Olmsted, Otter Tail, Ramsey, Red Lake, Roseau, St. Louis, Steele, Swift, Washington, and Winona.

Collection dates: April 3 – August 22.

Minnesota hosts: Reared from *Betula papyrifera* Marsh. Adults on *Betula* sp. and *Populus* sp. Additional larval hosts recorded as *B. alleghaniensis* Britt., *P. balsamifera* L., *P. deltoides* Bartr. ex Marsh, *P. grandidentata* Michx., and *P. tremuloides* Michx.

Collection method: Reared from *B. papyrifera* Marsh, collected on *Betula* and *Populus* logs, and as *C. fumipennis* prey.

6. *Agrilus arcuatus* (Say, 1825)

County records (*n* = 121): Anoka, Chisago, Crow Wing, Goodhue, Hennepin, Kanabec, Olmsted, Ramsey, and Washington.

Collection dates: June 16 – August 19.

Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Fagus grandifolia* Ehrh., *Quercus alba* L., and *Q. velutina* Lam. Adults also on *Carya* sp. and *Juglans nigra* L.

Collection method: Unspecified, collected at light, and as *C. fumipennis* prey.

7. *Agrilus audax* Horn, 1891

County records (*n* = 2): Goodhue and Chisago.

Collection dates: July 7 – July 29.

Minnesota hosts: Larval host recorded as *Ulmus fulva* Muhl. Adults also on *Quercus macrocarpa* Michx.

Collection method: *C. fumipennis* prey.

New state record: Chisago County, Taylor Falls Elementary, Taylor Falls, 45.406507 °N, -92.65621 °W, 29 July 2017, M. Hallinen, collected at *C. fumipennis* nesting site.

8. *Agrilus bilineatus* (Weber, 1801)

County records (*n* = 150): Anoka, Chisago, Crow Wing, Goodhue, Hennepin, Houston, Itasca, Olmsted, Ramsey, Steele, and Washington.

Collection dates: May 27 – August 10.

Minnesota hosts: Reared from *Quercus macrocarpa* Michx. and *Q. rubra* L. Adults collected on *Quercus* sp. Additional larval hosts recorded as *Q. alba* L., *Q. muehlenbergii* Engelm., and *Q. velutina* Lam. Adults also on *Abies* sp.

Collection method: Reared from *Q. macrocarpa* Michx and *Q. rubra* L., window traps in damaged *Quercus* sp., bait traps, rotary traps, and as *C. fumipennis* prey.

9. *Agrilus carpini* Knull, 1923

County records (n = 12): Chisago, Hennepin, Ramsey, Scott, and Washington.
Collection dates: June 11 – August 11.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Carpinus caroliniana* Walt., *Fagus grandifolia* Ehrh., and *Ostrya virginiana* (Mill.) K. Koch.
Collection method: Unspecified and as *C. fumipennis* prey.
New state record: Ramsey County, 11 June 1923, H.H. Knight.

10. *Agrilus celti* Knull, 1920

County records (n = 12): Houston and Ramsey.
Collection dates: May 30 – July 25.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Celtis occidentalis* L.
Collection method: Unspecified, collected at light, and as *C. fumipennis* prey.
New state record: Ramsey County, St. Anthony Park, 4 June 1912, collector unrecorded.

11. *Agrilus cephalicus* LeConte, 1860

County records (n = 1): Stearns.
Collection dates: June 22.
Minnesota hosts: MN larval host unknown. Adults recorded on *Cornus racemosa* Lam. and *Juglans nigra* L.
Collection method: Collected in trap during bark beetle survey.
New state record: Stearns County, 22 June 2004, B.R. MDA, 09DD trap# 053, Ag-PP bb survey.

12. *Agrilus cliftoni* Knull, 1941

County records (n = 1): Goodhue.
Collection dates: July 14.
Minnesota hosts: Larval hosts recorded as *Juglans nigra* L. Adults also on *Carya cordiformis* (Wangenh.) K. Koch, and *Cornus* sp.
Collection method: *C. fumipennis* prey.
New state record: Goodhue County, Wakondiota Park, Frontenac, 44.523776 °N, -92.33398 °W, 14 July 2018, collected at *C. fumipennis* nesting site, M. Hallinen.

13. *Agrilus crataegi* Frost, 1912

County records (n = 4): Faribault and Rice.
Collection dates: June 12 – June 20.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Amelanchier alnifolia* (Nutt.) Nutt. and *Crataegus* sp. Adults also on *C. douglasii* Lindl., *C. crus-galli* L., and *Juglans nigra* L.
Collection method: Unspecified.
New state record: Faribault County, 12 June 1922, H.H. Knight (n = 3).

14. *Agrilus crinicornis* Horn, 1891

County records (*n* = 2): Winona.
Collection dates: June 30.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Fagus grandifolia* Ehrh., *Gleditsia triacanthos* L., and *Quercus alba* L. Adults also on *Juglans nigra* L.
Collection method: Unspecified.

15. *Agrilus cuprescens* (Ménétries, 1832)

County records (*n* = 64): Anoka, Goodhue, Houston, Isanti, and Ramsey.
Collection dates: May 15 – August 21.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Rosa woodsii* Lindl. var. *ultramontana* (S. Wats.) Jeps. Additionally reported in *Rubrus* sp. (Westcott et al. 2015). Adults also on *Rosa blanda* Ait., *R. carolina* L., *R. multiflora* Thunb. ex Murr., and *R. rugose* Thunb.
Collection method: Unspecified.

16. *Agrilus cyanescens* Ratzeburg, 1837

County records (*n* = 2): Ramsey.
Collection dates: June 3.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Lonicera* L. sp. Adults also on *Symphoricarpos orbiculatus* Moench. and *Viburnum* sp. Recorded in Europe in association with *Alnus, Betual, Crataegus, Eryngium, Fagus, Quercus, Rosa,* and *Rubus* sp.
Collection method: Unspecified.

17. *Agrilus defectus* LeConte, 1860

County records: Literature record only (Hansen et al. 2011), Clearwater.
Collection dates: June 18.
Minnesota hosts: Larval hosts recorded as *Quercus alba* L. and *Q. muehlenbergii* Englem. Adults also on *Aesculus glabra* Willd., *Carya ovata* (Mill.) K. Koch, *Celtis occidentalis* L., *Crataegus* sp., *Gymnocladus dioicus* (L.) K. Koch, *Quercus macrocarpa* Michx., and *Q. velutina* Lam.
Collection method: Unspecified.

18. *Agrilus difficilis* Gory, 1841

County records (*n* = 41): Anoka, Chisago, Ramsey, and Washington.
Collection dates: July 18 – August 2.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Gleditsia triacanthos* L.
Collection method: All collected as *C. fumipennis* prey.
New state record: Washington County, Tilsen Park, Oakdale, 44.999932 °N, -92.966689 °W, 23 July 2014, B. Kuehn, collected at *C. fumipennis* nesting site.

19. *Agrilus egeniformis* Champlain and Knull, 1923

County records (*n* = 2): Ramsey.
Collection dates: July 20 – July 27.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Gleditsia triacanthos* L. Adults also on *Celtis occidentalis* L. and *Robinia pseudoacacia* L.
Collection method: All collected as *C. fumipennis* prey.
New state record: Ramsey County, Battle Creek Middle School, St. Paul, 44.947459 °N, -93.011506 °W, 20 July 2017, P. Haynes, collected at *C. fumipennis* nesting site.

20. *Agrilus egenus* Gory, 1841

County records (*n* = 34): Anoka, Clearwater, Hennepin, Olmsted, Ramsey, Washington, and Winona.
Collection dates: June 4 – July 31.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Robinia pseudoacacia* L.
Collection method: Unspecified and as *C. fumipennis* prey.
New state record: Washington County, 8 July 1911, collector unrecorded.

21. *Agrilus frosti* Knull, 1920

County records (*n* = 2): Hennepin and Olmsted.
Collection dates: Unknown.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Quercus* sp.
Collection method: Unspecified.

22. *Agrilus fulgens* LeConte, 1860

County records: Literature record only (Fisher 1928; Nelson et al. 2008).
Collection dates: Unknown.
Minnesota hosts: Larval host recorded as *Corylus americana* Walt.
Collection method: Unspecified

23. *Agrilus geminatus* (Say, 1823)

County records (*n* = 2): Houston.
Collection dates: June 1.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Quercus velutina* Lam. Adults also on *Gymnocladus dioicus* (L.) K. Kochl, *Juglans nigra* L., and *Quercus alba* L.
Collection method: Unspecified.

24. *Agrilus granulatus granulatus* (Say, 1823)
County records (*n* = 4): Anoka, Clearwater, and Chisago.
Collection dates: June 30 – July 1
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Betula* sp., *Populus deltoides* Marsh., *Populus deltoides* ssp. *monilifera* (Ait.) Eckenwalder, and *P. nigra* L.
Collection method: Unspecified and as *C. fumipennis* prey.

***Agrilus granulatus liragus* Barter and Brown 1949**
County records (*n* = 190): Anoka, Chisago, Crow Wing, Dakota, Goodhue, Hennepin, Lake, Ramsey, Stearns, and Washington.
Collection dates: June 28 – August 16.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Populus tremuloides* Michx.
Collection method: Unspecified and as *C. fumipennis* prey.

25. *Agrilus imbellis* Crotch, 1873
County records (*n*=1): Anoka.
Collection dates: July 20.
Minnesota hosts: Unspecified in collection records. Adults recorded on *Helianthemum canadense* (L.) Michx. and *Rudbeckia* sp.
Collection method: Unspecified.

26. *Agrilus impexus* Horn, 1891
County records (*n* = 1): Traverse.
Collection dates: August 4.
Minnesota hosts: Unspecified in collection records. Adults recorded on *Chrysothamnus* sp.
Collection method: Unspecified.

27. *Agrilus juglandis* Knull, 1920
County records (*n* = 5): Anoka, Chisago, and Winona.
Collection dates: June 30 – July 11.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Juglans cinerea* L. Adults also on *J. nigra* L.
Collection method: Unspecified and as *C. fumipennis* prey.
New state record: Winona County, King's Bluff, Great River Bluffs State Park, 30 June 1922, H.H. Knight.

28. *Agrilus lecontei lecontei* Saunders, 1871

County records (*n* = 4): Chisago, Goodhue, and Ramsey.

Collection dates: July 7 – July 27.

Minnesota hosts: Unspecified in collection records. Larval host recorded as *C. occidentalis* L.

Collection method: All collected as *C. fumipennis* prey.

New state record: Chisago County, Banta Park, Wyoming, 45.30746 °N, -92.992807 °W, 22 July 2017, M. Hallinen, collected at *C. fumipennis* nesting site.

29. *Agrilus masculinus* Horn, 1891

County records (*n* = 21): Clay, Faribault, Fillmore, Goodhue, Hennepin, Houston, Kandiyohi, Marshall, Meeker, Olmsted, Pipestone, Red Lake, and Washington.

Collection dates: May 9 – August 7.

Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Acer negundo* L., *A. platanoides* L., *A. rubrum* L., *A. saccharum* Marsh., *Aesculus glabra* Willd., and *Gleditsia triacanthos* L. Adults also on *Gymnocladus dioicus* (L.) K. Koch., *Rhus aromatic* Ait., and *Quercus velutina* Lam.

Collection method: Unspecified and Malaise trap.

30. *Agrilus nigricans* Gory, 1841

County records (*n* = 2): Chisago and Washington.

Collection dates: July 22 – August 2.

Minnesota hosts: Unspecified in collection records. Adults recorded on *Quercus rubra* L.

Collection method: All specimens as *C. fumipennis* prey.

New state record: Chisago County, Taylor Falls Elementary, Taylor Falls, 45.406507 °N, -92.65621 °W, 22 July 2017, E. Heeren.

31. *Agrilus obsoletoguttatus* Gory, 1841

County records (*n* = 61): Anoka, Chisago, Faribault, Goodhue, Hennepin, Houston, Isanti, Olmsted, Otter Tail, Ramsey, Washington, and Winona.

Collection dates: May 20 – August 1.

Minnesota hosts: Adult collected "on potatoes." Larval hosts recorded as *Aesculus glabra* Willd., *Carpinus caroliniana* Walt., *Carya* sp., *Gleditsia triacanthos* L., *Ostrya virginiana* (Mill.) K. Koch, *Quercus prinoides* Willd., and *Q. rubra.* Adults also on many different trees.

Collection method: Adult collected on potatoes, in bait trap, and as *C. fumipennis* prey.

32. *Agrilus osburni* Knull, 1937

County records (*n* = 2): Olmsted.
Collection dates: Unknown.
Minnesota hosts: Unspecified in collection records. Minnesota larval host unknown. Adults recorded on *Ostrya virginiana* (Mill.) K. Koch.
Collection method: Unspecified.
New state record: Olmsted County, C.N. Ainslie. Collection date unspecified. Identified by J.N. Knull in 1938.

33. *Agrilus otiosus* Say, 1833

County records (*n* = 16): Hennepin, Houston, Olmsted, Otter Tail, Ramsey, Red Lake, Stearns, Washington, and Winona.
Collection dates: May 27 – July 28.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Carya cordiformis* (Wangenh.) K. Koch, *C. ovata* (Mill.) K. Koch, *Juglans cinerea* L., and *J. nigra* L.
Collection method: Unspecified, in bark beetle trap, and as *C. fumipennis* prey.

34. *Agrilus parvus parvus* Saunders, 1870

County records (*n* = 96): Big Stone, Dakota, Hennepin, Olmsted, Pipestone, Ramsey, Scott, and Traverse.
Collection dates: June 6 – August 1.
Minnesota hosts: Unspecified in collection records. Adults recorded on *Amorpha fruticosa* L.
Collection method: Unspecified and Malaise trap.

35. *Agrilus pensus* Horn, 1891

County records (*n* = 17): Chisago, Clearwater, Ramsey, and Washington.
Collection dates: June 14 – July 30.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Betula nigra* L. Adults also on *Alnus incana* (L.) Moench, *A. viridis* (Chaix) DC. ssp. *crispa* (Ait.) Turrill, and *Ostrya virginiana* (Mill.) K. Koch.
Collection method: Unspecified and as *C. fumipennis* prey.

36. *Agrilus planipennis* Fairmaire, 1888

County records (*n* = 191): Anoka, Goodhue, Hennepin, Olmsted, and Ramsey.
Collection dates: June 23 – July 31.
Minnesota hosts: Reared from *Fraxinus pennsylvanica* Marsh. Additional larval hosts recorded as *F. americana* L., and *F. nigra* Marsh.
Collection method: Reared from cut *Fraxinus pennsylvanica* and as *C. fumipennis* prey.

37. *Agrilus politus* (Say, 1825)

County records (*n* = 114): Anoka, Cass, Chisago, Clearwater, Cook, Crow Wing, Goodhue, Hennepin, Hubbard, Lac qui Parle, Lake, Marshall, Olmsted, Polk, Ramsey, St. Louis, Todd, Wabasha, Washington, and Winona.
Collection dates: May 7 – August 21.
Minnesota hosts: Reared from ***Alnus incana* (L.) Moench ssp. *rugosa* (Du Roi) Clausen**. Additional larval hosts recorded as *Acer pensylvanicum* L. and *Salix lucida* Muhl. ssp. *lasiandra* (Benth.) E. Murr. Adults also on *Picea* sp. and *Thuja occidentalis* L.
Collection method: Reared from small branches of *Alnus incana* (L.) Moench ssp. *rugosa* (Du Roi) Clausen, by heating *Salix,* in bait trap, and as *C. fumipennis* prey.

38. *Agrilus pseudocoryli* Fisher, 1928

County records (*n* = 22): Anoka, Houston, Isanti, Lake, and Ramsey.
Collection dates: May 25 – July 14.
Minnesota hosts: Reared from *Corylus* hybrid. Additional larval hosts recorded as *C. americana* Walt. and *C. cornuta* Marsh. Adults also on *Abies* sp.
Collection method: Unspecified and reared from *Corylus* sp.
New state record: Houston County, Mississippi Bluff, 1-2 m N State Line, 30 May 1941, J.H. Hughes.

39. *Agrilus quadriguttatus quadriguttatus* Gory, 1841

County records (*n* = 41): Anoka, Chisago, Goodhue, Hennepin, Olmsted, Ramsey, and Washington.
Collection dates: July 12 – August 12.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Alnus* sp., *Salix nigra* Marsh., and *Salix* sp. Adults also on *Populus nigra* L. and *Salix interior* Rowlee.
Collection method: Most collected as *C. fumipennis* prey.
New state record: Ramsey County, 20 July 1932, N.C. Sullivan.

40. *Agrilus ruficollis* (Fabricius, 1787)

County records (*n* = 88): Anoka, Clearwater, Crow Wing, Faribault, Goodhue, Hennepin, Houston, Isanti, Itasca, Lake, Olmsted, Ramsey, Red Lake, Steele, Washington, and Winona.
Collection dates: May 26 – August 17.
Minnesota hosts: NJ specimens reported on ***Ulmus* sp.** Larval host recorded as domestic and wild *Rubus* sp.
Collection method: Unspecified.

41. *Agrilus transimpressus* Fall, 1925

County records (n = 4): Hennepin and Houston.
Collection dates: May 22 – June 1.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Juglans nigra* L. Adults also on *Carya* sp.
Collection method: Unspecified.

42. *Agrilus vittaticollis* (Randall, 1838)

County records (n = 2): Clearwater.
Collection dates: July 10.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Crataegus* sp. and *Malus* sp. Adults also on *Amelanchier arborea* (Michx. f.) Fern.
Collection method: Unspecified.

43. *Anthaxia cyanella* Gory, 1841

County records (n = 1): Goodhue.
Collection date: June 30.
Minnesota hosts: Larval hosts recorded as *Amelanchier arborea* (Michx. f.) Fern., *Betula nigra* L., *Gleditsia triacanthos* L., and *Vitis* sp. Adults also on *Crataegus* sp., *Ostrya virginiana* (Mill.) K. Koch, *Prunus americana* Marsh., *Rhus aromatica* Ait., and *Ulmus rubra* Muhl.
Collection method: Unspecified.
New state record: Goodhue County, Red Wing, 30 June 1923, A.T. Hertig.

44. *Anthaxia fisheri* Obenberger, 1928

County records (n = 3): Houston and Washington.
Collection dates: May 27 – June 14.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Prunus americana* Marsh. and *P. serotina* Ehrh. Adults also on *Acer* sp. and *Gleditsia triacanthos* L.
Collection method: Unspecified.
New state record: Washington County, Lakeland, 14 June 1922, H.H. Knight.

45. *Anthaxia inornata* (Randall, 1838)

County records (n = 77): Anoka, Clearwater, Cook, Isanti, Itasca, Lake, Marshall, and Mille Lacs.
Collection dates: April 25 – July 25.
Minnesota hosts: Larvae in ***Larix laricina* (Du Roi) K. Koch**. Adults collected on ***Angelica* sp**. Adults previously recorded on *Heterotheca villosa* (Pursh) Skinners, *Ranunculus acris* L., *Rosa* sp., *Pinus* sp., and *Tragopogon pratensis* L.
Collection method: Collected from dying *Larix laricina* (Du Roi) K. Koch, along Mille Lacs lake shore, and sweeping in woods.
Note: These specimens are identified as belonging to the *aeneogaster* group. This species group is in need of revision (Bílý and Kubáň 2010).

46. *Anthaxia quercata* (Fabricius, 1801)

County records (n = 64): Cass and Crow Wing.
Collection dates: July 1.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Crataegus chrysocarpa* Ashe, *Larix laricina* (DuRoi) K. Koch, *Picea mariana* B.S.P., *Pinus rigida* Mill., and *P. strobus* L. Adults also on *Corylus americana* Walt., *Prunus americana* Marsh., *Quercus rubra* L., and *Q. velutina* Lam.
Collection method: Unspecified.

47. *Anthaxia viridicornis* (Say, 1823)

County records (n = 18): Anoka, Faribault, Hennepin, Houston, Marshall, Olmsted, Ramsey, and Washington.
Collection dates: May 5 – June 25.
Minnesota hosts: Adults collected on ***Ulmus americana* L**. Larval hosts recorded as *Quercus* sp. and *Salix nigra* Marsh. Adults also on *Abies* sp. and *Populus* sp.
Collection method: Collected on *Ulmus americana* L. and in breeding cages.
New state record: Ramsey County, St. Anthony Park, May 5, 1912, Breeding Cage No. 1040D.

48. *Anthaxia viridifrons* Gory, 1841

County records: Literature record only (MacRae and Basham 2013), Ramsey.
Collection dates: Unknown.
Minnesota hosts: Collected from *Ulmus americana.* Larval hosts recorded as *Amelanchier arborea* (Michx. F.) Fern., *Carya ovata* (Mill.) K. Koch, *Morus* sp., and *Ulmus rubra* Muhl. Adults also on *Acer saccharum* Michx., *Carya cordiformis* (Wangenh.) K. Koch, *Celtis occidentalis* L., *Cornus racemosa* Lam., *Crataegus* sp., *Fraxinus americana* L., *Gleditsia triacanthos* L., *Juglans nigra* L., *Malus* sp., *Quercus alba* L., *Q. rubra* L., *Rubus* sp., and *Salix* sp.
Collection method: Collected from *Ulmus americana.*

49. *Brachys aerosus* (Melsheimer, 1845)

County records (n = 170): Anoka, Cass, Chisago, Clearwater, Crow Wing, Dakota, Faribault, Garrison, Goodhue, Hennepin, Houston, Isanti, Kanabec, Mille Lacs, Olmsted, Ramsey, Red Lake, St. Louis, Steele, Todd, Wadena, Washington, Winona, and Wyoming.
Collection dates: May 10 – August 2.
Minnesota hosts: Adults collected on ***Fraxinus americana* L**. and *Ulmus* sp. MI specimen collected on ***Ostrya*** sp. Larval host recorded as *Quercus rubra* L. var. *ambigua* (Gray) Fern. Adults also on *Acer* sp., *Corylus cornuta* Marsh., *Crataegus douglasii* Lindl., *C. punctata* Jacq., *Pinus banksiana* Lamb., *Populus termuloides* Michx., *Quercus alba* L., *Q. macrocarpa* Michx., *Q. rubra* L., *Q. velutina* Lam., *Ulmus americana* L., and *U. rubra* Muhl.
Collection method: Collected on *Fraxinus americana* L., on *Ulmus* leaves, and in bait trap.

50. *Brachys aeruginosus* Gory, 1841

County records (*n* = 11): Fillmore, Garrison, Lakeland, New Brighton, Olmsted, Ramsey, and Winona.
Collection dates: May 24 – July 10.
Minnesota hosts: Unspecified in collection records. Adults reported on *Carya* sp., *Quercus alba* L., and *Q. velutina* Lam.
Collection method: Unspecified.
New state record: Lakeland County, 14 June 1922, H.H. Knight.

51. *Brachys ovatus* (Weber, 1801)

County records (*n* = 38): Anoka, Chisago, Crow Wing, Grant, Hennepin, Mille Lacs, Morrison, Olmsted, Ramsey, and Washington.
Collection dates: May 19 – July 29.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Quercus rubra* L. var. *ambigua* (Gray) Fern. Adults also on *Quercus alba* L., *Q. rubra* L., and *Q. velutina* Lam.
Collection method: Unspecified, in bait trap, and as *C. fumipennis* prey.
New state record: Anoka County, St. Anthony Park, 26 May 1911.

52. *Buprestis aurulenta* Linnaeus, 1767

County records (*n* = 2): Hennepin, Olmsted.
Collection dates: March 1.
Minnesota hosts: *Pseudotsuga menziesii* (Mirb.) Franco.
Collection method: Unknown and collected on window sill of heated "porch" inside house.
New state record: Hennepin County, Minneapolis, 1 March 1934, H.S. Lamberton.
Note: This species is known to have a western distribution, and is recorded in the USA as far east as CO. These two Minnesota specimens likely represent a short term introduction in the 1930s and may have emerged from lumber or logs.

53. *Buprestis confluenta* Say, 1823

County records (*n* = 1): Cass.
Collection dates: July 23.
Minnesota hosts: Larval hosts recorded as *Populus deltoides* Marsh. and *P. tremuloides* Michx.
Collection method: Unspecified.
New state record: Cass County, Chippewa National Park, 23 July 2007, M. Abraham.

54. *Buprestis consularis* Gory, 1840

County records (n = 104): Cass, Chisago, Clearwater, Cook, Crow Wing, Goodhue, Hennepin, Isanti, Koochiching, Olmsted, Ramsey, Roseau, St. Louis, Steams, and Washington.

Collection dates: June 1 – August 26.

Minnesota hosts: Adults collected on ***Larix laricina* (Du Roi) K. Koch.** Larval hosts recorded as *Picea glauca* (Moench) Voss., *Pinus resinosa* Ait., and *P. rigida* Mill.

Collection method: Adults collected from "dry" *Larix laricina* and *Larix* logs, collected at light, in Lindgren funnel trap on *Pinus banksiana* Lamb. baited with alpha-pinene and bark beetle pheromones, and as *C. fumipennis* prey.

55. *Buprestis fasciata* Fabricius, 1787

County records (n = 39): Carlton, Cass, Clearwater, Cook, Goodhue, Itasca, Lake, Otter Tail, Pine, and St. Louis.

Collection dates: April 26 – September 7.

Minnesota hosts: Adults collected on ***Larix laricina* (Du Roi) K. Koch.** Adults also reported on *Abies* sp., *Picea* sp., and *Quercus* sp.

Collection method: Adults collected from dying *Larix laricina,* collected at light, in flight, and in Lindgren funnel trap on *Pinus banksiana* Lamb. baited with alpha-pinene and bark beetle pheromones.

56. *Buprestis maculativentris* Say, 1824

County records (n = 224): Aitkin, Beltrami, Carlton, Cass, Chisago, Clearwater, Cook, Crow Wing, Goodhue, Hennepin, Isanti, Itasca, Koochiching, Lake, Mille Lacs, Otter Tail, Ramsey, Rock, Sherburne, St. Louis, Stearns, Todd, Washington, and Wright.

Collection dates: June 3 – September 30.

Minnesota hosts: Adults collected on ***Larix laricina* (Du Roi) K. Koch,** *Picea* sp., and *Pinus resinosa* Ait. Larval hosts recorded as *Picea* sp., *Pinus resinosa* Ait., and *P. strobus* L.

Collection method: Adults collected on *Larix laricina* logs*, Picea sp.,* and *Pinus resinosa* Ait, in Lindgren funnel trap on *Pinus banksiana* Lamb. baited with alpha-pinene and bark beetle pheromones, and as *C. fumipennis* prey.

57. *Buprestis maculipennis* Gory, 1840

County records (n = 3): Clearwater and Ramsey.

Collection dates: June 17 – June 21.

Minnesota hosts: Unspecified in collection records. Larval host recorded as *Tsuga canadensis* (L.) Carrière.

Collection method: Unspecified.

58. *Buprestis salisburyensis* Herbst, 1801

County records (*n* = 8): Cass, Clearwater, Crow Wing, and Hennepin.
Collection dates: May 11 – July 18.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Pinus rigida* Mill.
Collection method: Unspecified.

59. *Buprestis striata* Fabricius, 1775

County records (*n* = 58): Beltrami, Cass, Chisago, Clearwater, Cook, Crow Wing, Goodhue, Ramsey, St. Louis, and Washington.
Collection dates: June 2 – July 30.
Minnesota hosts: Adults collected on ***Larix laricina* (Du roi) K. Koch.** MI specimen collected feeding on ***Pinus banksiana* Lamb**. needles. Larval hosts recorded as *Picea* sp., *Pinus rigida* Mill., *P. strobus* L., and *Tsuga canadensis* (L.) Carr.
Collection method: Adults collected on dying *Larix laricina*, in Lindgren funnel trap on *Pinus banksiana* Lamb. baited with alpha-pinene and bark beetle pheromones, and as *C. fumipennis* prey.

60. *Buprestis sulcicollis* (LeConte, 1860)

County records (*n* = 1): Cook.
Collection dates: July 5 – August 2 (trap interval).
Minnesota hosts: Unspecified. Larval hosts recorded as *P. rigida* Mill. and *P. strobus* L.
Collection method: Lindgren funnel trap on *Pinus banksiana* Lamb.

61. *Chalcophora fortis* LeConte, 1860

County records (*n* = 16): Aitkin, Cass, Clearwater, Hubbard, Itasca, Morrison, Olmsted, and St. Louis.
Collection dates: June 10 – August 29.
Minnesota hosts: Unspecified. Larval host recorded as *Pinus strobus* L.
Collection method: Unspecified.

62. *Chalcophora liberta* (Germar, 1824)

County records (*n* = 31): Beltrami, Cass, Clearwater, Itasca, Pine, and St. Louis.
Collection dates: May 20 – September 12.
Minnesota hosts: Adults collected on ***Pinus banksiana* Lamb**. Larval hosts recorded as *P. resinosa* Ait. and *P. strobus* L.
Collection method: Unspecified and collected on *Pinus banksiana* foliage.

63. *Chalcophora virginiensis* (Drury, 1770)

County records (*n* = 143): Anoka, Beltrami, Carlton, Cass, Clearwater, Cook, Crow Wing, Itasca, Lake, Morrison, Pine, Stearns, Wadena, and Wright.
Collection dates: May 16 – October 5.
Minnesota hosts: Adults collected on ***Larix laricina* (Du roi) K. Koch., *Pinus resinosa* Ait.,** and *P. strobus* L. Larval hosts recorded as *P. rigida* Mill. and *P. strobus* L.
Collection method: Unspecified, on *Larix laricina* (Du roi) K. Koch, on *Pinus* sp, and in Lindgren funnel trap on *Pinus banksiana* Lamb. baited with alpha-pinene and bark beetle pheromones.

64. *Chrysobothris adelpha* Harold, 1869

County records (*n* = 5): Goodhue, Houston, Olmsted, and Ramsey.
Collection dates: May 23 – July 11.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Amelanchier arborea* (Michx. f.) Fern. and *Carya ovata* (Mill.) K. Koch. Adults also on *Acer platanoides* L., *Fraxinus pennsylvanica* Marsh., and *Quercus* sp.
Collection method: Malaise trap and as *C. fumipennis* prey.
New state record: Ramsey County, St. Paul, 1 July 1933, E.M. Freeman.

65. *Chrysobothris azurea* LeConte, 1857

County records (*n* = 5): Chisago, Hennepin, and Olmsted.
Collection dates: July 3 – July 24.
Minnesota hosts: Unspecified in MN specimens. NJ specimens recorded on ***Ulmus* sp**. Larval hosts recorded as *Acer* sp., *Alnus incana* (L. Moench ssp. *rugosa* (DuRoi) Clausen, *Amelanchier arborea* (Michx. f.) Fern., *Celastrus scandens* L., *Juglans nigra* L., *Pinus* sp., *Prunus virginiana* L., *Quercus bicolor* Willd., *Rhus glabra* L., and *Vitis* sp. Adults also on *Acer saccharum* Marsh., *A. platanoides* L., *Cornus racemosa* Lam., *Crataegus* sp., *Fraxinus americana* L., *F. pennsylvanica* Marsh., *Gleditsia triacanthos* L., *Pinus strobus* L., *Populus tremuloides* Michx., and *Quercus velutina* Lam.
Collection method: All collected as *C. fumipennis* prey.
New state record: Hennepin County, Forest Hills Elementary, 44.881184 °N, -93.450027 °W, 7 July 2017, P. Haynes, collected at *C. fumipennis* nesting site.

66. *Chrysobothris cribaria* Mannerheim, 1837

County records (*n* = 10): Chisago, Clearwater, Cook, Crow Wing, and Lake.
Collection dates: May 25 – August 26.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Pinus resinosa* Ait., *P. rigida* Mill., *P. strobus* L., and *P. sylvestris* L.
Collection method: Unspecified and in Lindgren funnel trap on *Pinus banksiana* Lamb.

67. *Chrysobothris dentipes* (Germar, 1824)

County records (n = 103): Cass, Clearwater, Cook, Goodhue, Hennepin, Itasca, Lake, Olmsted, Ramsey, and St. Louis.

Collection dates: May 28 – August 26.

Minnesota hosts: Adults collected on *Larix laricina* (Du roi) K. Koch. and *Pinus strobus* L. WI specimen collected on ***Pinus banksiana* Lamb.** Larval hosts recorded as *Abies balsamea* (L.) Mill., *Larix laricina* (Du roi) K. Koch., and *Pinus strobus* L.

Collection method: Adults collected on *Larix laricina* (Du roi) K. Koch. logs and *Pinus strobus* L., in Lindgren funnel trap on *Pinus banksiana* Lamb., and as *C. fumipennis* prey.

68. *Chrysobothris femorata* (Olivier, 1790)

County records (n = 204): Anoka, Chisago, Clearwater, Cook, Dakota, Goodhue, Hennepin, Houston, Lac qui Parle, Lake, Olmsted, Otter Tail, Ramsey, St. Louis, Steele, Washington, Winona, and Wright.

Collection dates: May 5 – August 19.

Minnesota hosts: Adults collected on ***Larix laricina* (Du roi) K. Koch.** and *Quercus* sp. Larval hosts recorded as *Acer negundo* L., *A. rubrum* L., *A. saccharinum* L., *Amelanchier arborea* (Michx. f.) Fern., *Carpinus caroliniana* Walt., *Celtis occidentalis* L., *Crataegus* sp., *Fraxinus pennsylvanica* Marsh., *Juglans cinerea* L., *J. nigra* L., *Malus* sp., *Populus tremuloides* Michx., *Prunus domestica* L., *Quercus alba* L., *Sorbus americana* Marsh., *Tilia americana* L. var. *americana,* and *Ulmus americana* L.

Collection method: Collected from dying *Larix laricina* (Du roi) K. Koch., from window traps in damaged *Quercus* sp., in bait trap, breeding cages, at light, Malaise trap, in Lindgren funnel trap on *Pinus banksiana* Lamb., and as *C. fumipennis* prey.

69. *Chrysobothris harrisi* Hentz, 1827

County records: Literature record only (Nelson et al. 2008).

Collection dates: Unknown.

Minnesota hosts: Larval hosts recorded as *Picea glauca* (Moench) Voss and *Pinus strobus* L.

Collection method: Unknown.

70. *Chrysobothris mali* Horn, 1886

County records: Literature record only (Nelson et al. 2008).

Collection dates: Unknown.

Minnesota hosts: Larval hosts recorded as *Acer negundo* L., *A. rubrum* L., *A. saccharinum* L., *Aesculus hippocastanum* L., *Betula* sp., *Corylus* sp., *Malus* sp., *Populus deltoides* Bartr. ex Marsh., *P. nigra* L., *Prunus americana* Marsh., *P. domestica* L., *Ribes rubrum* L., *Rosa* sp., *Sorbus aucuparia* L., *Ulmus americana* L., and *U. glabra* Huds.

Collection method: Unknown.

71. *Chrysobothris neopusilla* Fisher, 1942

County records (*n* = 2): Chisago and Washington.
Collection dates: June 30 – July 17.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Picea mariana* B.S.P. Adults also on *P. glauca* (Moench) Voss.
Collection method: All collected as *C. fumipennis* prey.
New state record: Washington County, Marine Elementary Ballfield, 45.2027 °N, -92.7727 °W, 17 July 2017, M. Hallinen, collected at *C. fumipennis* nesting site.

72. *Chrysobothris orono* Frost, 1920

County records (*n* = 1): Crow Wing.
Collection dates: July 13.
Minnesota hosts: Larval hosts recorded as *Pinus banksiana* Lamb. and *P. resinosa* Ait.
Collection method: *C. fumipennis* prey.
New state record: Crow Wing County, Nisswa Elementary School, 46.519723 °N, -94.285988 °W, 13 July 2017, M. Hallinen, collected at *C. fumipennis* nesting site.

73. *Chrysobothris pusilla* Gory and Laporte, 1837

County records (*n* = 4): Cook.
Collection dates: August 12 – 27 (trap interval).
Minnesota hosts: Larval hosts recorded as *Pinus rigida* Mill. and *Tsuga canadensis* (L.) Carr. Adults on *Pinus banksiana* Lamb. and *P. strobus* L.
Collection method: All collected in Lindgren funnel trap on *Pinus banksiana* Lamb.

74. *Chrysobothris quadriimpressa* Gory and Laporte, 1837

County records (*n* = 1): Houston.
Collection dates: May 31.
Minnesota hosts: Larval hosts recorded as *Juglans nigra* L., *Quercus alba* L., and *Q. rubra* L.
Collection method: Unspecified.

75. *Chrysobothris rotundicollis* Gory and Laporte, 1837

County records (*n* = 14): Chisago, Clearwater, Cook, Crow Wing, Goodhue, Hennepin, Todd, and Washington.
Collection dates: June 28 – August 12.
Minnesota hosts: Collected on ***Pinus banksiana* Lamb.** log. Larval hosts recorded as *Larix laricina* (Du roi) K. Koch., *Pinus rigida* Mill., and *P. strobus* L.
Collection method: On *Pinus banksiana* Lamb. log, in Lindgren funnel trap on *P. banksiana* Lamb. and as *C. fumipennis* prey.

76. *Chrysobothris rugosiceps* Melsheimer, 1845

County records (*n* = 10): Anoka, Cass, Chisago, Clearwater, Houston, Isanti, Wadena, and Washington.
Collection dates: May 13 – July 29.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Quercus alba* L., *Q. macrocarpa* Michx. and *Q. velutina* Lam. Adults also on *Carya ovata* (Mill.) K. Koch.
Collection method: Unspecified and as *C. fumipennis* prey.

77. *Chrysobothris scabripennis* Gory and Laporte, 1837

County records (*n* = 42): Clearwater, Cook, Itasca, Lake, and Roseau.
Collection dates: May 5 – August 21.
Minnesota hosts: Collected from ***Larix laricina* (Du roi) K. Koch.** Larval hosts recorded as *Picea galuca* (Moench) Voss, *Pinus strobus* L., and *Tsuga canadensis* (L.) Carr.
Collection method: Unspecified and collected from dying *Larix laricina* and *L. laricina* logs.

78. *Chrysobothris sexsignata* Say, 1839

County records (*n* = 102): Anoka, Chisago, Cook, Crow Wing, Goodhue, Hennepin, Houston, Olmsted, Pipestone, Ramsey, and Washington.
Collection dates: May 24 – August 11.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Acer rubrum* L., *A. saccharum* Marsh., *Amelanchier arborea* (Michx. f.) Fern., *Betula alleghaniensis* Britt., *B. nigra* L., *Carya ovata* (Mill.) K. Koch, *Celtis occidentalis* L., *Fagus* sp., *Fraxinus americana* L., *F. nigra* Marsh., *F. pennsylvanica* Marsh., *F. quadrangulata* Michx., *Gleditsia tricanthos* L., *Juglans cinerea* L., *J. nigra* L., *Larix laricina* (Du roi) K. Koch, *Picea mariana* (Mill.) B.S.P., *Pinus rigida* Engelm., *Quercus alba* L., *Q. bicolor* Willd., *Q. macrocarpa* Michx., *Q. muehlenbergii* Engelm., *Tsuga canadensis* (L.) Carr., *Ulmus rubra* Muhl., and *Vitus* sp. Adults also on *Acer saccharinum* L. and *Sorbus aucuparia* L.
Collection method: Collected at light, Malaise trap, in Lindgren funnel trap on *Pinus banksiana* Lamb., and as *C. fumipennis* prey.

79. *Chrysobothris shawnee* Wellso and Manley, 2007

County records (*n* = 6): Chisago and Washington.
Collection dates: July 16 – August 8.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Quercus* sp. Adults also on *Fraxinus pennsylvanica* Marsh., *Quercus alba* L., *Q. bicolor* Willd., *Q. rubra* L., and *Q. velutina* Lam.
Collection method: All collected as *C. fumipennis* prey.
New state record: Washington County, Northdale Park, Oakdale, 45.024136 °N, -92.972632 °W, 8 August 2016, J. Schultz.

80. *Chrysobothris trinervia* Kirby, 1837

County records (*n* = 40): Aitkin, Clearwater, Cook, Hennepin, Itasca, Lake, Otter Tail, and St. Louis.
Collection dates: May 28 – August 17.
Minnesota hosts: Collected from *Larix laricina* (Du roi) K. Koch. Larval hosts recorded as *Larix laricina* (Du roi) K. Koch, *Picea* sp., and *Pseudotsuga menziesii* (Mirb.) Franco. Adults also on *Abies* sp., *Pinus banksiana* Lamb., and *P. strobus* L.
Collection method: Collected from dying *Larix laricina* and *Larix laricina* logs and in Lindgren funnel trap on *Pinus banksiana* Lamb.

81. *Chrysobothris verdigripennis* Frost, 1910

County records (*n* = 2): Chisago and St. Louis.
Collection dates: June 15.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Picea abies* (L.) Karst and *Tsuga canadensis* (L.) Carr. Adults also on *Abies balsamea* (L.) Mill., *Fagus grandifolia* Ehrh., *Picea glauca* (Moench) Voss, and *Pinus* sp.
Collection method: Unspecified.
New state record: St. Louis County, 15 June 1936, Daggy R.H.

82. *Chrysobothris viridiceps* Melsheimer, 1845

County records (*n* = 50): Anoka, Arden Hills, Chisago, Goodhue, Hennepin, Houston, Olmsted, Otter Tail, Ramsey, and Washington.
Collection dates: May 29 – July 29
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Acer rubrum* L., *Pinus* sp., *Quercus alba* L., *Q. macrocarpa* Michx., and *Quercus* sp. Adults also *Acer saccharinum* L., *Carya ovata* (Mill.) K. Koch, *Quercus bicolor* Willd., *Q. velutina* Lam., and *Ulmus americana* L.
Collection method: Unspecified and as *C. fumipennis* prey.

83. *Dicerca asperata* (Laporte and Gory, 1837)

County records (*n* = 23): Chisago and Washington.
Collection dates: May 5 – August 11.
Minnesota hosts: Adults collected from *Quercus* sp. Larval host recorded as *Quercus* sp.
Collection method: Collected from beating *Quercus* sp. and as *C. fumipennis* prey.
New state record: Washington County, 11 May 1940, W.A. Connell, beating oak.

84. *Dicerca callosa callosa* Casey, 1909

County records (*n* = 15): Beltrami, Clearwater, and Crow Wing.
Collection dates: June 14 – August 9.
Minnesota hosts: Collected on "weeds." Adults recorded on *Betula* sp., *Populus tremuloides* Michx., and *Salix* sp.
Collection method: Adults collected on weeds and as *C. fumipennis* prey.

85. *Dicerca caudata* LeConte, 1860

County records (*n* = 290): Aitkin, Anoka, Becker, Cass, Chisago, Clearwater, Cook, Crow Wing, Duluth, Goodhue, Hennepin, Itasca, Lyon, Mille Lacs, Olmsted, Otter Tail, Pine, Ramsey, St. Louis, Stearns, and Washington.
Collection dates: May 3 – August 13.
Minnesota hosts: Collected from ***Larix laricina (*Du roi) K. Koch.** Larval hosts recorded as *Alnus* sp. and *Betula nigra* L. Adults also on *Alnus incana* (L.) Moench, *Crataegus* sp., and *Prunus virginiana* L.
Collection method: Unspecified and as *C. fumipennis* prey.

86. *Dicerca divaricata* (Say, 1823)

County records (*n* = 281): Aitkin, Anoka, Beltrami, Cass, Chisago, Clearwater, Cook, Crow Wing, Fillmore, Goodhue, Hennepin, Itasca, Kanabec, Kandiyohi, Lac qui Parle, Lake, Mille Lacs, Nicollet, Norman, Olmsted, Otter Tail, Pine, Ramsey, Red Lake, St. Louis, Stearns, Washington, and Wright.
Collection dates: May 4 – October 21.
Minnesota hosts: Collected from ***Larix laricina (*Du roi) K. Koch** and *Populus* sp. Larval hosts recorded as *Acer pennsylvanicum* L., *A. saccharum* Marsh., *Betula lenta* L., *Fraxinus americana* L., *F. nigra* Marsh., *Ostrya virginiana* (Mill.) K. Koch., *Quercus alba* L., *Q. rubra* L., and *Ulmus americana* L. Adults also on *Abies* sp., *Acer negundo* L., *A. rubrum* L., *Betula alleghaniensis* Britt., *Fagus grandifolia* Ehrh., *Pinus* sp., *Populus balsamifera* L., and *Prunus* sp.
Collection method: Collected from *Larix laricina* (Du roi) K. Koch logs, in Lindgren funnel trap on *Pinus banksiana* Lamb., and as *C. fumipennis* prey.

87. *Dicerca lepida* LeConte, 1857

County records (*n* = 1): Ramsey.
Collection dates: Unspecified.
Minnesota hosts: Larval host recorded as *Crataegus chrysocarpa* Ashe var. *chrysocarpa* and *Ostrya virginiana* (Mill.) K. Koch. Adults also on *Quercus* sp.
Collection method: Unspecified.
New state record: Ramsey County. Collection date unspecified. Identified by J.N. Knull in 1922.

88. *Dicerca lugubris* LeConte, 1860

County records (*n* = 16): Carlton, Clearwater, Cook, Crow Wing, and St. Louis.
Collection dates: May 31 – August 2.
Minnesota hosts: Unspecified in collection records. Adults recorded on *Pinus banksiana* Lamb.
Collection method: In Lindgren funnel trap on *Pinus banksiana* Lamb. baited with alpha-pinene and bark beetle pheromones and as *C. fumipennis* prey.

89. *Dicerca lurida* (Fabricius, 1775)

County records (*n* = 47): Chisago, Goodhue, Hennepin, Houston, Nicollet, Olmsted, Ramsey, and Washington.
Collection dates: May 15 – August 11.
Minnesota hosts: Unspecified in MN specimens. MD specimen collected on ***Salix* sp.** and MI specimen collected on *Carya ovata* (Mill.) K. Koch. Larval hosts recorded as *Alnus incana* (L.) Moench ssp. *rugosa* (DuRoi) Clausen, *Carpinus caroliniana* Walt., *Carya cordiformis* (Wangenh.) K. Koch, *Tilia americana* L. Adults also on *Quercus alba* L. and *Q. velutina* Lam.
Collection method: Unspecified and as *C. fumipennis* prey.

90. *Dicerca pugionata* (Germar, 1824)

County records (*n* = 4): Cass, Clearwater, and Houston.
Collection dates: May 27 – July 16.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Alnus incana* (L.) Moench, *Hamamelis virginiana* L., and *Physocarpus opulifolius* (L.) Maxim.
Collection method: Unspecified.
New state record: Clearwater County, Itasca, 16 July 1923, S.A. Graham.

91. *Dicerca sexualis* Crotch, 1873

County records (*n* = 1): Ramsey.
Collection dates: May 16.
Minnesota hosts: Larval host recorded as *Pseudotsuga menziesii* (Mirb.) Franco.
Collection method: Unspecified.
New state record: Ramsey County, St. Paul, 16 May 1941, E.R. Sterner.
Note: This species, identified in the MN collection by W.J. Chamberlin, is a western species recorded in the USA in CA, ID, MT, NV, OR, and WA. MN is significantly outside of this range, so this specimen may represent an erroneous record or a short term introduction.

92. *Dicerca tenebrica* (Kirby, 1837)

County records (*n* = 350): Aitkin, Anoka, Beltrami, Carlton, Cass, Chisago, Clearwater, Cook, Crow Wing, Dakota, Goodhue, Hennepin, Houston, Itasca, Kittson, Koochiching, Lac qui Parle, Lake, Lake of the Woods, Mille Lacs, Olmsted, Otter Tail, Pennington, Pine, Polk, Ramsey, St. Louis, Wadena, Washington, and Winona.

Collection dates: April 26 – September 1.

Minnesota hosts: Adults collected on ***Larix laricina (*Du roi) K. Koch, *Pinus banksiana* Lamb., *Populus alba*** **L**., *Populus* sp., and flowers of ***Sonchus arvensis* L.** Larval host recorded as *Populus grandidentata* Michx. Adults also on *Populus tremuloides* Michx.

Collection method: Adults collected on foliage and flowers, in Lindgren funnel trap on *Pinus banksiana* Lamb. baited with alpha-pinene and bark beetle pheromones, washed ashore on Lake Superior, and as *C. fumipennis* prey.

93. *Dicerca tenebrosa tenebrosa* (Kirby, 1837)

County records (*n* = 126): Anoka, Bemidji, Cass, Chisago, Clearwater, Cook, Crow Wing, Hennepin, Itasca, Olmsted, Pine, Ramsey, St. Louis, Stearns, and Washington.

Collection dates: May 18 – August 29.

Minnesota hosts: Collected on ***Picea pungens* Engelm.** Adults also on *Abies balsamea* (L.) Mill., *Picea glauca* (Moench) Voss, *Pinus banksiana* Lamb., *P. resinosa* Ait., and *Pseudotsuga menziesii* (Mirb.) Franco.

Collection method: Collected on *Picea pungens* Engelm, in Lindgren funnel trap on *Pinus banksiana* Lamb., washed ashore on Lake Superior, and as *C. fumipennis* prey.

94. *Eupristocerus cogitans* (Weber, 1801)

County records (*n* = 57): Anoka, Chisago, Crow Wing, Hennepin, Lake, Pine, Ramsey, Wadena, and Washington.

Collection dates: June 2 – August 18.

Minnesota hosts: Collected on *Alnus* sp. Larval hosts recorded as living *Alnus incana* (L.) Moench, *Alnus incana* (L.) Moench ssp. *rugosa* (Du Roi) R.T. Clausen, and *Betula nigra* L.

Collection method: Unspecified, collected on *Alnus* sp., and as *C. fumipennis* prey.

New state record: Pine County, Willow River, 7 August 1922, E. Hoffman.

95. *Melanophila acuminata* (DeGeer, 1774)

County records (*n* = 75): Anoka, Beltrami, Carlton, Cass, Clearwater, Cook, Crow Wing, Hennepin, Kanabec, Kandiyohi, Koochiching, Lake, Olmsted, Otter Tail, Pine, Polk, Ramsey, Red Lake, Roseau, and St. Louis.
Collection dates: May 27 – September 30.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Abies balsamea* (L.) Mill., *Betula alleghaniensis* Britt., *Picea glauca* (Moench) Voss., *Pinus resinosa* Ait., *P. strobus* L., and *Thuja occidentalis* L. Adults also on *Pinus ponderosa* Laws.
Collection method: Unspecified and in Lindgren funnel trap on *Pinus banksiana* Lamb.

96. *Pachyschelus confusus* Wellso, Manley and Jackman 1976

County records (*n* = 29): Anoka, Isanti, and Ramsey.
Collection dates: May 30 – August 19.
Minnesota hosts: Unspecified in MN specimens. MI specimens collected on *Lespedeza* leaves. Adults recorded on *Lespedeza capitata* Michx.
Collection method: Unspecified and sweeping in mixed meadow.

97. *Pachyschelus laevigatus* (Say, 1833)

County records (*n* = 51): Anoka, Chisago, Isanti, Olmsted, Otter Tail, Ramsey, Wabasha, and Washington.
Collection dates: June 4 – September 16.
Minnesota hosts: Collected on *Lespedeza capitata* Michx., and ***Centaurea stoebe* L**. Larval hosts recorded as *Lespedeza* sp. Adults also on *Desmodium canescens* (L.) DC., *D. cuspidatum* (Muhl. ex Willd.) DC. ex Loud., and *D. glutinosum* (Muhl. ex Willd.) Wood.
Collection method: Unspecified, collected on *Lespedeza capitata* Michx. and *Centaurea stoebe* L., and in pine plantation.
New state record: Chisago County, 16 September 1911.

98. *Pachyschelus purpureus purpureus* (Say, 1833)

County records (*n* = 3): Hennepin and Ramsey.
Collection dates: May 20 – May 25.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Geranium maculatum* L. and *Lespedeza* sp. Adults also on *Carya* sp., *Fraxinus americana* L., and *Juglans nigra* L.
Collection method: Unspecified and collected in poplar woods.

99. *Phaenops abies* (Champlain and Knull, 1923)

County records (*n* = 1): Carlton.
Collection dates: June 22 – 29 (trap interval).
Minnesota hosts: Adults recorded on *Abies balsamea* Mill.
Collection method: Lindgren funnel trap baited with alpha-pinene and (+/-)-seudenol.
New state record: Carlton County, South side, Ditch Banks Rd. T49, R19W, S18, 22 June – 29 June 2001 (trap interval), J. Warren, Lindgren funnel trap baited with (-)-alpha-pinene and (+/-)-seudenol.

100. *Phaenops aeneola* (Melsheimer, 1845)

County records (*n* = 11): Chisago, Crow Wing, Hubbard, and Washington.
Collection dates: July 3 – July 31.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Pinus resinosa* Ait. Adults also on *Picea* sp. and *Pinus banksiana* Lamb.
Collection method: Lindgren funnel trap baited with alpha-pinene and ethanol and as *C. fumipennis* prey.

101. *Phaenops drummondi drummondi* (Kirby, 1837)

County records (*n* = 78): Clearwater, Cook, Hennepin, Isanti, Itasca, and St. Louis.
Collection dates: May 25 – August 26.
Minnesota hosts: Collected from *Larix laricina (*Du roi) K. Koch. Larval hosts also recorded as *Abies* sp., *Picea* sp., and *Pseudotsuga* sp.
Collection method: Reared out of imported *Larix occidentalis* Nutt., collected from *Larix laricina* (Du roi) K. Koch, and in Lindgren funnel trap on *Pinus banksiana* Lamb.

102. *Phaenops fulvoguttata* (Harris, 1829)

County records (*n* = 17): Aitkin, Clearwater, Hubbard, Lake, Olmsted, Otter Tail, and St. Louis.
Collection dates: June 18 – August 16.
Minnesota hosts: From *Larix laricina (*Du roi) K. Koch. Larval hosts also recorded as *Abies balsamea* (L.) Mill., *Picea glauca* (Moench) Voss, *P. mariana* (Mill.) B.S.P., *Pinus strobus* L., and *Tsuga canadensis* Carr.
Collection method: Unspecified and collected from *Larix laricina (*Du roi) K. Koch in association with *Dendroctonus simplex*.
New state record: Lake County, Q-S WRC, Sec. 9, Twp. 64N, Rge. 10W, Basswood Lake, 8 August 1950, J.W. Barnes.

103. *Poecilonota cyanipes* (Say, 1823)

County records (*n* = 91): Aitkin, Anoka, Chisago, Cook, Crow Wing, Dakota, Goodhue, Lake, Polk, Ramsey, Stearns, and Washington.
Collection dates: June 12 – August 16.
Minnesota hosts: Collected from *Populus* sp. Larval hosts recorded as *P. deltoides* Marsh., *P. grandidentata* Michx., *P. tremuloides* Michx., *Robinia pseudoacacia* L., and *Salix nigra* Marsh.
Collection method: Unspecified, collected from *Populus* sp., and as *C. fumipennis* prey.

104. *Poecilonota ferrea* (Melsheimer, 1845)

County records (*n* = 21): Chisago, Clearwater, Crow Wing, Goodhue, Hennepin, Stearns, and Washington.
Collection dates: June 16 – August 5.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Populus* sp.
Collection method: Unspecified and as *C. fumipennis* prey.

105. *Poecilonota thureura* (Say, 1832)

County records (*n* = 1): Goodhue.
Collection dates: June 28.
Minnesota hosts: Larval hosts recorded as *Salix nigra* Marsh. and *Salix* sp.
Collection method: *C. fumipennis* prey.
New state record: Goodhue County, Twin Bluffs Middle School, Red Wing, 44.544774 °N, -92.54571 °W, 28 June 2018, collected at *C. fumipennis* nesting site, M. Hallinen.

106. *Ptosima walshii* LeConte, 1863

County records (*n* = 1): Ramsey.
Collection dates: May.
Minnesota hosts: Larval host recorded as *Quercus macrocarpa* Michx.
Collection method: Unspecified.

107. *Spectralia gracilipes* (Melsheimer, 1845)

County records (*n* = 26): Anoka, Goodhue, Hennepin, Olmsted, Ramsey, Washington, and Winona.
Collection dates: June 14 – July 27.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Fraxinus* sp., *Ostrya virginiana* (Mill.) K. Koch, *Quercus alba* L., *Q. bicolor* Willd., and *Q. macrocarpa* Michx. Adults also on *Celtis* sp., *Crataegus* sp., and *Solidago* sp.
Collection method: Unspecified and as *C. fumipennis* prey.

108. *Taphrocerus cylindricollis* Kerremans, 1896

County records (*n* = 6): Fillmore, Houston, Mille Lacs, and Pine.
Collection dates: May 3 – June 27.
Minnesota hosts: Unspecified in collection records. Hosts unknown.
Collection method: Unspecified.
New state record: Pine County, Mouth of Snake River, 3 May 1941, J.B. Hughes.

109. *Taphrocerus gracilis* (Say, 1825)

County records (*n* = 43): Anoka, Cass, Chisago, Clearwater, Fillmore, Goodhue, Hennepin, Houston, Mille Lacs, Olmsted, Ramsey, Steele, Wabasha, Washington, and Winona.
Collection dates: April 22 – August 21.
Minnesota hosts: Unspecified in collection records. Larval host recorded as *Bolboschoenus fluviatilis* (Torr.) Soják. Adults also on *Cephalanthus occidentalis* L. and *Rumex verticillatus* L.
Collection method: Unspecified. Collected in oak grove and tamarack swamp.

110. *Taphrocerus schaefferi* (Nicolay and Weiss, 1920)

County records (*n* = 2): Anoka and Houston.
Collection dates: May 21 – July 15.
Minnesota hosts: Unspecified in collection records. Larval hosts recorded as *Cyperus* sp. and *C. esculentus* L. Adults also on *Carex vulpinoidea* Michx.
Collection method: Unspecified.
New state record: Houston County, 21 May 1938, H.E. Miliron.

Discussion

Of the species reported in this checklist, several are known pests native to North America, including *Agrilus anxius*, *A. bilineatus*, *A. difficillis*, *A. granulatus, A. ruficollis,* and *Chrysobothris femorata* (Solomon 1995). A total of 41 specimens of *A. difficillis,* a pest of *Gleditisia* (honeylocust) species, were collected for the first time in Minnesota during *C. fumipennis* surveys, mostly in Anoka and Ramsey counties (n = 35). These recent finds indicate that it was either already present in Minnesota, but not detected by previous survey methods, or has recently established in the state. *Cerceris fumipennis* is reported to collect species such as *Actenodes acornis* and *A. simi* not commonly collected with other techniques such as insect traps or beating (Paiero et al. 2012).

The only destructive species recorded in Minnesota that is not native to North America was EAB. The majority of the 191 EAB specimens were collected using *C. fumipennis* surveys, with 58 beetles collected in Ramsey County and 68 in Olmsted County alone. At one site in Olmsted County, EAB comprised 65 out of 67 total beetles collected, indicating either a reduction in buprestid diversity due to EAB presence, a preference by *C. fumipennis* for EAB as prey, or a tendency for *C. fumipennis* to return to EAB-infested trees.

While *C. fumipennis* has been utilized broadly for buprestid surveys, its limitations are well studied. *Cerceris fumipennis* is known to prefer nesting in hard packed sandy substrates such as baseball diamonds and walking trails, limiting survey extent by both wasp environmental preference and the labor required to find nesting aggregations (Nalepa et al. 2012; Careless et al. 2014; Kimoto et al. 2015b). MDA employees and Minnesota Wasp Watcher volunteers scouted for *C. fumipennis* nests, focusing their efforts around Minneapolis and Saint Paul, leading to a reported concentration of beetles in these counties that likely does not reflect buprestid distribution in the state. Despite search efforts and the desire to utilize *C. fumipennis* to track EAB in northern Minnesota, no large *C. fumipennis* nesting aggregations were found around Duluth, Minnesota, where EAB was discovered in 2015. This absence may be attributable to climate, as Minnesota exists close to the northern edge of the known range for *C. fumipennis,* although rarely colonies are found as far north as Lillooet, British Columbia, Canada (50.7°N) (Kimoto et al. 2015a). In addition to these limitations, wasps also have a size bias when hunting buprestids, as prey weight varies with wasp weight and larger wasps collect a broader weight range than smaller wasps (Nalepa and Swink 2018). We found that wasps collected beetles with lengths between 4.48 mm and 21.01 mm (Chapter 2), which is consistent with previous reports (Hellman and Fierke 2014). These size limitations exclude buprestid genera such as *Taphrocerus* that are typically too small to be *C. fumipennis* prey and *Chalcophora* that are typically too large (Hellman and Fierke 2014). However, our sample collection across space (i.e. 12 different counties) and through time (i.e. 2014-2018) ensured robust results that contend with a species composition hunted by *C. fumipennis* that can vary from year to year (Swink et al. 2014).

The future of buprestid biodiversity after EAB-induced ash mortality is uncertain. While the increased amount of dying and dead ash material may provide substrate for those species able to reproduce in or feed on *Fraxinus* species in the short term, in the long term there may be negative impacts on these species, or the potential for host switching amongst species with just one or two hosts in addition to ash (Gandhi and Herms 2010). It has been suggested that EAB may result in reduced buprestid biodiversity, as EAB may attract higher numbers of buprestid predators and parasitoids to a given location (Boone et al. 2008; Carlton et al. 2018). There may also be the potential for species to increase in abundance in the absence of ash due to compensatory growth of non-ash species. *Acer* and *Ulmus* species were reported to experience the most growth in EAB-disturbed forests (Flower et al. 2013), so buprestids utilizing these genera as hosts may increase in abundance.

Due to the nature of our sampling technique, it is difficult to elucidate long-term changes in buprestid populations in Minnesota, as buprestids were sampled with very different methods and inconsistently over the past century. Future sampling with *C. fumipennis* would provide the best method of measuring population change over time, especially in those Minnesota counties where EAB has not yet established. Due to the labor and time involved in finding and monitoring wasp colonies, it has been suggested that *C. fumipennis* sampling can be combined with more cost-effective methods such as the use of the purple prism traps commonly used for EAB detection in order to collect the broadest range of buprestids (Nalepa et al. 2015).

Historical records from the University of Minnesota Department of Entomology's Insect Collection complement *C. fumipennis* survey data to provide a more accurate picture of the buprestid populations in Minnesota. While 12 new state records were collected through *C. fumipennis* sampling, most state records (29) had been previously collected and organized in the university system, often many decades ago, but not reported. As the first such buprestid checklist created for the state, this list provides a baseline for future work as well as a historical record of buprestid presence in Minnesota. This list will make it easier to determine the timing of potential future non-native buprestid introductions, range expansions of species native to North America, and the potential future extirpation of species previously found in Minnesota.

Chapter 2

Prey diversity of foraging *Cerceris fumipennis* Say (Hymenoptera: Crabronidae) and factors influencing buprestid diversity and species distributions in Minnesota

Summary

Many jewel beetles (Coleoptera: Buprestidae) play an important ecological role in wood decomposition and nutrient cycling. Compared with other saproxylic species, buprestids are considered cryptic as they are difficult to sample and identify. As a result, factors that influence buprestid diversity and distribution are poorly understood. This is especially true in urban forests, which may be unique fragmented and contain unique species distributions. We utilized the native ground nesting hunting wasp *Cerceris fumipennis* to survey buprestids at 20 urban sites in Minnesota, USA. We collected a total of 1,939 beetles consisting of 11 genera and 51 species, including 10 new state records for the state of Minnesota. *Agrilus* was the most common genus collected, followed by *Dicerca.* Species richness tended to decrease in sites with many emerald ash borer, *Agrilus planipennis* (EAB), which may reflect a potential tendency of wasps to return preferentially to high density infestations of EAB. We found buprestid species richness positively correlated with several site-level variables, such as the number of dead trees, within a 200 m radius around each *C. fumipennis* nesting site. Positive correlations between certain buprestid species and a number of tree genera offer new insights into potential host associations in this understudied family. Our work illustrates how *C. fumipennis* can be utilized for general buprestid surveys in urban areas to better understand the distribution of this cryptic family.

Introduction

Saproxylic species are associated with dead or dying wood during some part of their life cycle, and thus play a vital role in forest carbon cycling (Grove 2002). These insects help break down slow-to-decay woody material, returning nutrients such as nitrogen, carbon, phosphorus, among others, back to the soil (Hammond et al. 2001). In Europe, saproxylic insects compose a disproportionate percentage of threatened species, to the extent that a large number are locally extinct and many more face potential extinction (Grove 2002; Nieto and Alexander 2010; Seibold et al. 2015). As a group, saproxylic species are dominated by beetles (Coleoptera) (Speight 1989; Hammond 1997). In Western Australia all jewel beetles (Coleoptera: Buprestidae) were listed as protected fauna under the 1978 Wildlife Conservation Act, likely due to their "collectable" status (New 2007). Many jewel beetles have beautiful iridescent elytra, or wing coverings, as adults, even though the larval grub-like life stage in dead or decaying wood is relatively nondescript.

To protect vulnerable species and predict the distribution of pest species, factors that influence diversity and abundance must first be understood. Several studies, have shown, for example, that the abundance of buprestids is positively correlated with fresh coarse woody debris, sun exposure, and less intensive management regimes in the surrounding habitat, with the exception of "conservation" thinning treatments that result in increased canopy openness (Wermelinger et al. 2002; Ulyshen and Hanula 2009; Paillet et al. 2010; Redilla and McCullough 2017; Gran and Götmark 2019). Most work on saproxylic communities to date has been conducted in Europe, where the decline of European saproxylic species has been attributed to habitat fragmentation caused by the elimination of old growth forests, fire suppression policies, and excessive forestry "hygiene" practices that include the removal of dead wood (Kaila et al. 1997; Grove 2002; Davies et al. 2008). In comparison to Europe, the composition of North American saproxylic communities is less well studied (Jacobs et al. 2007; Gandhi et al. 2009; Ulyshen and Hanula 2009).

Almost all studies on saproxylic species globally have concentrated on forests with various silvicultural or harvesting treatments. In contrast, less is known about the saproxylic community in urban forests, which have several unique characteristics (Peuhu et al. 2019). Urban forests contain unique species assemblages, reflecting the introduction and prevalence of exotic flora, pollution, and human disturbance (McIntyre 2000; McKinney 2002). Native species in urban habitats may be replaced by nonnative species, leading to increased species homogenization at the urban core (Blair 2001; Burton and Samuelson 2005; McKinney 2006). Urban forests are often "patchy" environments, consisting of isolated fragments that may negatively impact species richness and abundance depending on the dispersal capabilities of the species in question (Weller and Ganzhorn 2004; Fujita et al. 2008; Jones and Leather 2012; Fattorini and Galassi 2016). Conversely, green spaces such as urban forests may act as refuges that preserve biodiversity (Zapparoli 1997; Angold et al. 2006; Jonsell 2012). In one of the few studies on urban saproxylic species, Fattorini and Galassi (2016) found saproxylic tenebrionid abundance to be positively correlated with green space area and forest surface in the urban green spaces of Rome, Italy.

Of all saproxylic feeders, knowledge of buprestid beetles is especially lacking outside of occasional pestiferous species (Barter 1957; Haack and Benjamin 1982). In

North America, interest in buprestid beetle ecology has increased with the arrival of the invasive emerald ash borer (EAB), *Agrilus planipennis* Fairmaire, given its potential to displace native insects that feed on ash trees (*Fraxinus* spp.) (Gandhi and Herms 2010; Domingue and Baker 2012). Overall, buprestid beetles are more difficult to sample and identify relative to other families within Coleoptera such as cerambycids and carabids (Redilla and McCullough 2017). Sampling methods for saproxylic species include pitfall traps, flight-intercept traps, yellow pan traps, and window traps, all of which infrequently catch buprestids (Okland et al. 1996; Lassau et al. 2005; Wermelinger et al. 2007; Gandhi et al. 2009).

Baiting traps with semiochemicals such as host volatiles has been used to detect the presence of EAB, but has also been used to sample other buprestid species (Marshall et al. 2010; Skvarla and Holland 2011; Domingue and Baker 2012). Deployment of traps with sex pheromones, used commonly for other wood borers such as bark beetles (Lindgren 1983; Byers et al. 1984; Vité and Baader 1990; Ross and Daterman 1998; Gandhi et al. 2009), has been hampered by the apparent lack of pheromones in the Buprestidae outside of the recent discovery of a short-range volatile pheromone in EAB (Bartelt et al. 2007; Silk et al. 2011). When adult buprestids are collected, they can be difficult to identify to species. A positive identification often requires examination of male genitalia or knowledge of the larval host plant (Paiero et al. 2012). As such, some studies have employed such tedious sampling methods as dissecting insects directly from snags and woody material (Saint-Germain et al. 2007).

The specialist buprestid hunting wasp *Cerceris fumipennis* Say (Hymenoptera: Crabronidae) provides a novel collection opportunity as the wasp is known to capture a large size range of buprestids and does not sting humans (Marshall et al. 2005; Careless et al. 2014; Hellman and Fierke 2014). Females of *C. fumipennis* hunt almost exclusively for beetles in the buprestid family (Rutledge et al. 2011). Wasps confirm prey identity through contact with cuticular hydrocarbons specific to buprestids (Rutledge et al. 2014), sting adult beetles to induce paralysis, and then carry prey back to subterranean nests using their mandibles, legs, and special morphological adaptations known as "buprestid clamps" (Nalepa and Swink 2015). *Cerceris fumipennis* is a mass-provisioning species that sequesters multiple beetles in an individual nest cell before laying a single egg on the venter of the topmost beetle and closing off the completed cell (Scullen and Wold 1969; Kurczewski and Miller 1984). Although wasps in the genus *Cerceris* are solitary, many species, including *C. fumipennis,* are known to form nesting aggregations, with multiple females nesting in close proximity and competing for nests (Scullen 1965; Mueller et al. 1992). Nesting aggregations are commonly found in places with flat, hard packed, and sandy soil, including human-disturbed sites such as baseball diamonds, walking trails, and parking lots (Evans 1971; Kurczewski and Miller 1984; Nalepa 2012).

Humans have collected beetles from *C. fumipennis* nesting sites for many decades (Grossbeck 1912; Scullen 1965; Evans 1971; Kurczewski and Miller 1984; Mueller et al. 1992). Since the early 2000s interest has increased due to the potential to utilize the wasp as a natural surveillance tool to track the spread of EAB as it moves across the United States (Marshall et al. 2005; Careless et al. 2014). This use of the predatory behavior of one species to locate another has since been termed "biosurveillance" (Careless 2009; Nalepa et al. 2012; Rutledge et al. 2013; Swink et al. 2013; Careless et al. 2014). These wasps appear to be efficient hunters. For example, Nalepa et al. (2015) collected over nine times more beetles and five times more buprestid species with *C. fumipennis* compared to purple prism trap sampling in North Carolina, USA. Moreover, perhaps given their obligate feeding relationship, their summer flight period coincides with buprestid flight activity for most species (Chapter 1, Klingeman et al. 2015).

In this paper, we collected buprestid beetles at 20 nesting aggregations of *C. fumipennis* over two years to determine the composition of buprestid community assemblages in urban forests in Minnesota, USA. We then examined surrounding site-level variables potentially associated with buprestid diversity and species distributions at 12 of these sites, including counts of live trees identified to genus, dead trees, and measurements of tree diameter at breast height (DBH) surrounding each nesting aggregation of *C. fumipennis*. Our objective was to determine whether buprestid beetles acquired through biosurveillance would be positively correlated with habitat variables such as known host types in the surrounding urban environment, a relatively under-sampled space compared to natural forests. We discuss new findings that provide knowledge of a baseline community assemblage in rapidly changing urban forests undergoing the extirpation of all *Fraxinus* species (up to 75% of existing tree cover) and show how statistical associations may reveal host associations for previously unstudied species.

Materials and Methods

Buprestid collection

We picked sites from a list of locations of nesting aggregations of *C. fumipennis* within Minnesota compiled by volunteers with the citizen science group "Wasp Watchers." These volunteers scouted *C. fumipennis* sites in collaboration with University of Minnesota Extension and Minnesota Department of Agriculture (MDA) staff from 2014 - 2018. Scouts looked for the distinctive ring of tumulus surrounding holes approximately 0.5 – 0.7 cm in diameter as evidence of *C. fumipennis* nesting activity (Careless 2008). Sites were confirmed positive for *C. fumipennis* only after a female wasp with its distinctive facial markings was positively identified. We selected only "large" sites (>10 nests in previous years) to ensure efficient buprestid sampling. Additionally, we only surveyed nesting aggregations at baseball diamonds due to ease of access. One site, Jake Regan Park, was excluded from analysis due to an interruption in sampling caused by a baseball tournament.

Adult *C. fumipennis* began to emerge in early July in 2017 and mid-June in 2018, consistent with a degree day model developed by Rutledge et al. (2015). Wasps began foraging for buprestids after an initial period of nest excavation, mating, and feeding that lasted several days. We collected beetles at 10 sites during the summer of 2017, and 10 different sites during the summer of 2018 (Fig. 2.1, Table 2.1). We sampled at each site three times during the active flight period of the wasp. We only sampled on sunny days when wasps were foraging. If no wasp activity was observed, we returned the following day. One or two surveyors monitored wasp activity at each site from 11 am to 3 pm during 2017 and from 11 am to 2 pm during 2018, when wasps are most active (Careless et al. 2014).

Beetles were collected by netting all wasps returning to their nests. When a wasp was netted, its prey was collected from the bottom of the net, as *C. fumipennis* tends to drop its buprestid prey upon contact. Actively netting wasps does not change their foraging rate (Careless et al. 2014). Wasps sometimes abandon beetles at the mouth of their nests, either to prevent the sequestration of parasitized prey or due to nest usurpation by a competing female (Mueller et al. 1992). We collected all discarded beetles found. We also augmented collections from the same 20 sites with specimens contributed by Wasp Watchers volunteer surveyors, who sampled sites from 2015-2018 in the same manner. Buprestids were pinned and identified to species, with uncertain identifications confirmed by Dr. Norman Woodley (USDA ARS Systematic Entomology Lab, Beltsville, MD).

In 2017, we measured the head capsule width of 345 female wasps and the length of the beetles they carried to elucidate how the size of prey may vary with wasp size. *Cerceris fumipennis* head width is known to be highly correlated with overall body weight (Ohl and Thiele 2007; Nalepa and Swink 2018). The relationship between head width of female *C. fumipennis* and beetle length was analyzed with linear regression.

Tree surveys

To understand how the buprestids hunted by *C. fumipennis* reflect surrounding urban forest habitat, from June to July 2018 we censused all trees >10 cm diameter at breast height (DBH) in a 200 meter radius around each of 12 of our sampling sites (Fig. 2.2). Two hundred meters is a conservative estimate of the hunting radius of *C. fumipennis* (Nalepa et al. 2013). We recorded tree genus, DBH, and condition (e.g. missing bark, alive/dead, standing/fallen). We included relatively "fresh" fallen tree material, defined as material with bark, leaves, or little fragmentation. We did not include decayed coarse woody debris (CWD) or logs, as "old" CWD has not been shown to be correlated with buprestid diversity or abundance in previous work (Redilla and McCullough 2017). Because our sites were urban, it was sometimes difficult to obtain access to trees to measure them directly. In those cases, we visually estimated the DBH of trees. We validated our estimates by comparing individual visual estimations against true DBH in a training exercise using publicly accessible trees, and found there was no statistically significant difference between the two (Appendix 2.1). We then used DBH to calculate the basal area in m^2.

Statistical analysis

We generated individual-based rarefaction curves, which give the expected richness in a randomly selected subsample of the larger sample pool (Hurlbert 1971; Heck et al. 1975; Sanders 1986). This method helps control for sampling effort when comparing species richness across sites, as using raw species richness alone is known to introduce bias based on sampling conditions and/or effort (Gotelli and Colwell 2001). While we were systematic in our sampling scheme, sampling effort differed depending on the number of wasps actively hunting, and additional bias was potentially introduced by augmenting the data with effort from volunteers. Two sites were excluded from richness analyses due to low numbers of buprestids collected (<40 beetles).

In developing our rarefactions curves, we followed Chao and Jost (2012), Colwell et al. (2012), and Chao et al. (2014), who developed methods for extrapolating rarefaction curves based on estimated asymptotic species richness and sample completeness that have proven advantageous at estimating differences in species richness between communities. We used the R Package "iNEXT" (Hsieh et al. 2016) based on this work to predict sample coverage and extrapolate species richness estimates at our sites (Chao et al. 2014). We determined that to achieve a sample coverage of 90% at our sites, the required sample size ranged from 5 to 90 beetles depending on the site, with an average of 55 beetles. To achieve a sample coverage of 95%, the sample size needed ranged from 27 to 219 beetles per site, with an average of 100 beetles (Appendix 2.2). We chose to extrapolate our rarefaction curves and give species richness estimates at double a sample size of 44 beetles, as 44 reflected the site with the lowest number of specimens procured among sites included (Autumn Grove Park). Hence, we obtained predictions of species richness as if we had sampled 88 beetles per site, resulting in an extrapolated estimate for six sites and an interpolated estimate for the remaining four sites (analogous to a traditional rarefaction).

We created linear regression models examining the relationships between estimated buprestid species richness and variables reflecting surrounding urban habitat. These variables included total trees, total dead, barkless, and fallen trees, the basal areas of these tree categories, and tree genus richness. The response variable for each of the ten sites, estimated species richness based on an actual or hypothetical sample of 88 beetles, had an associated measure of variability. For each regression model, we captured the variability inherent in the species richness estimates by using the 95% confidence intervals of predicted species richness to construct normal distributions that characterized species richness, one for each site. We sampled a richness estimate for each of these distributions such that we had 10 representative response values, and utilized them in a regression against a candidate explanatory variable of interest (e.g. the effect of number of trees on estimated species richness). We recorded the resulting estimates of the intercept and slope from this regression, and repeated the procedure 999 times such that we obtained a data distribution of intercept and slope estimates. We then truncated the top and bottom 2.5% of the resulting 1000 slope and intercept estimates, retaining the middle 95%. We report the minimum (i.e., 2.5% quantile), maximum (i.e. 97.5% quantile), median, and mean of these values, highlighting those with a slope interval that does not overlap zero (i.e. a statistically significant relationship between response and predictor). All statistical analyses were carried out in R (R Core Team 2018).

In addition to species richness, we analyzed the total number of buprestid beetles captured. If *C. fumipennis* hunts buprestids in a way that reflects the true diversity of beetles present in an area, its prey should be positively correlated with the composition of surrounding host trees. To determine whether there was a relationship between certain tree genera and buprestid species, we used poisson regression (i.e. a generalized linear model (GLM) with a log link) with buprestid count as the response variable and count or basal area (m^2) of tree genera as the explanatory variable. We did not conduct analyses on buprestid species with fewer than 15 individuals collected per site. Due to the large number of models explored we only report correlations between buprestid species and tree genera with a significance level below $\alpha = 0.01$, and report correlations between tree genera and known hosts ≥ 0.6. Of those species with counts under 15 individuals, there were no statistically significant relationships with tree genera, so are not reported. We excluded tree genera with a total of three or fewer individuals recorded.

Results

The average number of *C. fumipennis* nests at our 20 sites ranged from 9 to 220, with a mean of 60 nests per site throughout the sampling period (Table 2.1). Overall, a total of 51 species from 11 genera were collected, comprising 1,939 individuals, with 1,871 identifiable to species (Table 2.2). The most common species collected was *Dicerca caudata* with 255 individuals, followed by *Dicerca divaricata* with 213 individuals. We collected the emerald ash borer (*A. planipennis*) at nine sites; it was the most commonly collected *Agrilus* species at 151 individuals. The most common genus collected was *Agrilus* at 736 beetles, closely followed by *Dicerca* at 702 beetles (Fig. 2.3). Eight species were represented by a single individual. Buprestids collected at our sites included 10 new records for the state of Minnesota (bolded in Table 2.2). Including additional beetles collected by citizen science volunteers at other nesting aggregations, sampling at *C. fumipennis* sites has resulted in a total of 12 state records (Table 2.2, Chapter 1).

Wasp size and beetle preference

There was a large size range of beetles caught, reflecting wasps of different sizes. Wasps' head widths ranged from 2.9 mm to 5.7 mm, and beetle prey ranged from 4.5 mm to 21.0 mm in length. Larger wasps (head width >4.8 mm) almost exclusively captured larger genera such as *Buprestis* and *Dicerca,* while smaller wasps (head width <4.2 mm) almost exclusively captured smaller genera such as *Agrilus* and *Chrysobothris* (Fig. 2.4). While every site had wasps large enough to hypothetically capture "large" beetles, wasps hunted just a single beetle in the genus *Dicerca* at the two sites where wasps had the smallest maximum head widths (4.7 mm, sites AG and FH). Many intermediatedly sized wasps hunted for both large and small genera, capturing both *Dicerca* and *Agrilus* species.

Species richness

These urban sites showed very different extrapolated species richness curves (Fig 2.5). On each curve, the asymptote (where the slope becomes horizontal) represents the predicted true number of species per site. The predicted true number of species at a site ranged from 5 at site GE to 38 at site MB, although the variation in asymptotic estimates increased greatly with extrapolations in predicted sample size, represented by the 95% confidence intervals for each site. The flattest slopes, indicating a given sampling technique quickly collects all species it can at a site, were found at sites where the majority of species picked up by *C. fumipennis* consisted of EAB (AG and GE).

The number of trees per site ranged from 421 to 1772, with an average of 1002 trees within 200 m of the focal nesting aggregation (Fig. 2.6). Some urban sites were located in suburban neighborhoods, which contained mostly ornamental trees planted in yards of private residences. Others contained more abundant and less managed tree cover, although still in close proximity to private residences, schools, and parks. The number of dead trees per site ranged from 0 to 93, with an average of 48 dead trees (Fig. 2.6). There was one site (GE) without any dead trees within 200 m of its *C. fumipennis* nesting aggregation, standing or fallen. Canopy composition was relatively diverse, with genus richness ranging from 16 to 23 genera per site. No site was dominated by any one tree genus; the most numerous genera consisted of *Acer* spp. at three sites, *Pinus* spp. at three sites, *Populus* spp. at three sites, and *Quercus* spp. at three sites. No site contained over 50% of these genera and most sites (10/12) contained under 30% of any one genus.

In single variable regressions, we found positive linear relationships between adjusted species richness (at 88 buprestids per site) and several variables, including total number of trees and total basal area (BA) of trees, total number and total BA of dead trees, total number and total BA of fallen trees, and total number and total BA of barkless trees (Table 2.3). For example, our models estimate that one might find one new species of buprestid for every 96 trees in the surrounding 200 m habitat (i.e. one divided by mean slope estimate of 0.0104 in Table 2.3). We also found a positive linear relationship between adjusted species richness and average number of *C. fumipennis* nests.

Buprestid species and tree genera relationships

There was a negative relationship between adjusted buprestid species richness and tree genera richness. This pattern suggests that the presence of more tree genera was not associated with increased diversity of buprestids, although we did note a number of positive correlations with between specific species of buprestids and certain tree species. Of all buprestid species collected, 20 had counts over 15 beetles at the 12 sites where we measured tree variables, and all 20 buprestid species exhibited a positive relationship with at least one genus of tree (Table 2.4). Moreover, 13 out of the 20 buprestid species had a positive relationship with at least one known host tree genera for that species (α = .01), denoted in bold. Several tree species were highly positive correlated with each other. For species without a known host present, we noted the presence of a positively correlated host on site with an asterisk (Table 2.4).

Discussion

Our study reveals several advantages of exploiting the prey-gathering behavior of *Cerceris fumipennis* for biodiversity studies in urban environments. First, this technique shows promise as a way to detect new invasive species (Swink et al. 2015). Effective sampling methods for buprestids are needed to detect these and unforeseen threats, as non-indigenous wood boring insects have been increasingly detected in the U.S. over the past 50 years (Aukema et al. 2010). In our study, *Agrilus* was the genus captured with the highest level of frequency (Figure 2.3), and is also the genus that contains the most pestiferous species of concern within the Buprestidae (Solomon 1995). For example, *C. fumipennis* was particularly adept at procuring emerald ash borer (*A. planipennis*), with much lower buprestid species richness at sites where we collected large numbers of EAB (sites GE and ZP). This pattern suggests that *C. fumipennis* may preferentially return to trees infested by EAB once detected, and/or that high numbers of EAB may attract higher levels of buprestid predators and parasitoids that reduce buprestid diversity in an area (Boone et al. 2008; Carlton et al. 2018).

Moreover, while we captured 18 different *Agrilus* species, including five new records for the state (Chapter 1, Table 2.2), the absence of other high-profile non-native *Agrilus* species facilitates a baseline community inventory in advance of potential arrival. *Agrilus sulcicollis* Lacordaire is one invasive buprestid present in North America (Jendek and Grebennikov 2009) not detected in our study. As *A. sulcicollis* prefers more moribund *Quercus* (oak) tissue than the native *A. bilineatus,* it was predicted to be nonaggressive in North Amercia but has recently been reported high numbers in Michigan, suggesting its density and range may be expanding (Petrice and Haack 2013; Redilla and McCullough 2017). Likewise, *A. biguttatus* Fabricius, which attacks oaks in Europe, is also considered a substantial risk to North American forest resources (Moraal and Hilszczanski 2000; Davis et al. 2005).

Another advantage of using *C. fumipennis* in biosurveillance is the potential to elucidate potential host genera of buprestid beetles, particularly for buprestid species which have not been well studied to date. For example, we found a positive correlation between counts of buprestid species *Buprestis consularis, Buprestis maculativentris,* and *Dicerca tenebrosa* and *Thuja* species of trees. It seems reasonable to hypothesize that these buprestids, relatively specialized on conifer hosts (Nelson et al. 2008), could be utilizing *Thuja* spp. in either the larval or adult stage. Because so many buprestid species are generalists (Nelson et al. 2008), it is likely that at least some of the correlations we found represent newly discovered host associations. We note, however, that results should be interpreted carefully, and on a case-by-case basis. Unexpected positive correlations between buprestid species and tree genera may simply reflect spurious positive correlations between habitat variables (Jacobs et al. 2007). For example, we found correlations between EAB and *Fraxinus* (ash), its host, but also *Celtis, Gleditsia, Morus, Ostrya, Sorbus, Syringa,* and *Tilia* species. EAB is a known specialist on *Fraxinus* spp. in North America (Haack et al. 2002; Peterson and Cipollini 2017); EAB larvae or adults are not using tree genera not closely related to *Fraxinus* spp. as hosts. The associated genera above tend to be planted ornamentally within urban sites.

Irrespective of potential spurious correlations, our results point to a strong relationship between the total number of dead trees and buprestid diversity collected by *C. fumipennis* as measured by species richness. The total number of dead trees around nesting aggregations was the most significant predictor of rarified species richness, and is the most biologically relevant factor of those we measured, as many species of buprestids have obligate development in stressed or dying host material (Bright 1987). More brood material likely supports more species. Basal area (BA) of dead trees in the 200 m around our sites also showed a positive relationship with rarified species richness, but to a lesser degree, suggesting that total number of trees in an area may be more important than their size. *Agrilus anxius* preferentially utilizes branches of around 18 mm (Solomon 1995) but substrate size preferences for most genera in our study remain unknown.

While rarefaction curves allow some conclusions about species richness at these sites, relative species abundances remain unknown. Numbers likely vary with habitat, but also sampling effort of the foraging wasps. Wasp aggregations are affected by soil moisture, density, and/or pressure from kleptoparasites (Rosenheim 1990; Strohm et al. 2001; Careless et al. 2010). Examination of the intercepts in Table 2.3 provides estimates of the number of buprestid species present when no trees are present within 200 m from the regression lines. Predictions of four to nine buprestid species at sites with no trees within 200 m, and from seven to ten species with no dead trees (from intercept ranges in Table 2.3) suggest that *C. fumipennis* may fly farther than 200 m to forage. Careless et al. (2014) found that two out of eight wasps returned to nests when released from 2 km away, suggesting a maximum foraging radius just under 2 km.

Every sampling method has inherent bias, and size preference is a known bias in utilizing *C. fumipennis* for biosurveillance (Hellman and Fierke 2014). Other sampling methods, such as the use of EAB prism traps in combination with *C. fumipennis* biosurveillance, could help provide the most accurate picture of buprestid communities in an area (Nalepa et al. 2015). Additional work into mate searching behaviors of the Buprestidae could lead to new, more effective trap designs for this family (Lelito et al. 2007, 2011; Domingue and Baker 2012).

This is one of the few studies specifically examining buprestid community assemblages and associated habitat factors in an urban environment. Urban areas represent unique risks, as they contain a higher density of humans, and humans are often responsible for introducing and spreading non-native pest species (Nicolay and Weiss 1918; McIntyre 2000). However, they also represent unique opportunities for conservation, as they can sustain reservoirs of biodiversity in an increasingly urbanized environment (Zapparoli 1997; Angold et al. 2006; Jonsell 2012). Urban forests are not as heavily managed as production forests, and so tend to contain higher quantities of dead wood and more structural diversity than those planted for wood harvesting (Siitonen 2012). High buprestid diversity noted in this work underscores the fact that urban forests provide significant habitat for several saproxylic species. Such trends, in concert with effective sampling using biosurveillance, may be useful to inform management strategies protective of threatened saproxylic species, such as maintaining a diverse age structure of trees or allowing dead trees to persist on the landscape within safety constraints (Harmon 2001; Mortimer and Kane 2004; Toivanen et al. 2007; Davies et al. 2008).

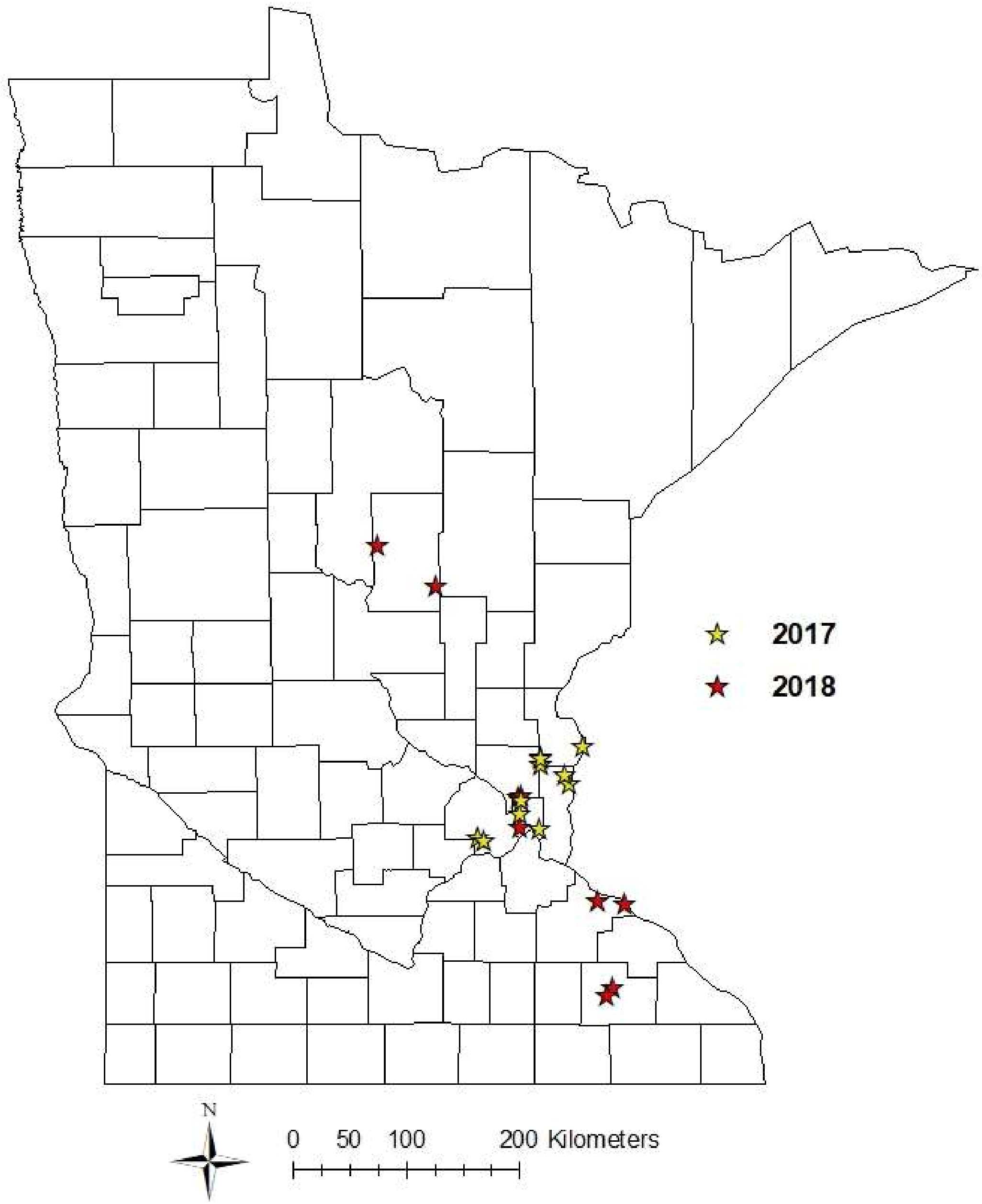

Figure 2.1. Location of the 20 *C. fumipennis* nesting aggregations sampled during the summers of 2017 and 2018 in Minnesota, USA.

Table 2.1. Sites with *C. fumipennis* nesting aggregations visited for sampling in the summers of 2017 and 2018 in Minnesota, USA. Number of *C. fumipennis* nests were averaged over three sampling visits. Sites where surrounding tree canopy features were measured for comparison to species richness are bolded. Jake Regan Park, Forest Hills Elementary, and Scenic Heights Elementary were excluded from diversity analysis due to low numbers of buprestids collected (<40 individuals).

Site Name	Site Abbr.	County	GPS coordinates	Average nests
Autumn Grove Park	**AG**	**Ramsey**	**45.03215, -93.1584**	**15**
Austin Park	AP	Anoka	45.12579, -93.1674	24
Battle Creek Middle School	**BC**	**Ramsey**	**44.94746, -93.0115**	**13**
Banta Park	**BP**	**Chisago**	**45.30746, -92.9928**	**53**
Emerald Hills Park	EH	Olmsted	44.05245, -92.4155	26
Forest Hills Elementary	**FH**	**Hennepin**	**44.88117, -93.4502**	**9**
Galtier Elementary	**GE**	**Ramsey**	**44.95819, -93.1546**	**17**
Golden Lake Elementary	**GL**	**Anoka**	**45.13271, -93.1491**	**34**
Jake Regan Park	JR	Crow Wing	46.29519, -93.8294	14
Marine Elementary Ballpark	**MB**	**Washington**	**45.20270, -92.7727**	**121**

Nisswa Elementary	NE	Crow Wing	46.51972, -94.2860	175
New Scandia T-Ball Field	**NS**	**Washington**	**45.25013, -92.8030**	**27**
Scenic Heights Elementary	**SH**	**Hennepin**	**44.90132, -93.4970**	**10**
Swenson Park	**SP**	**Chisago**	**45.33976, -92.9910**	**31**
Twin Bluff Middle School	TB	Goodhue	44.54477, -92.5457	152
Taylor Falls	TF	Chisago	45.40647, -92.6562	163
Turtle Lake Elementary	**TL**	**Ramsey**	**45.11045, -93.1497**	**41**
Tolzmann Park	**TP**	**Chisago**	**45.34722, -92.9937**	**220**
Wakondiota Park	WP	Goodhue	44.52378, -92.3340	42
Zumbro Park	ZP	Olmsted	44.00386, -92.4709	19

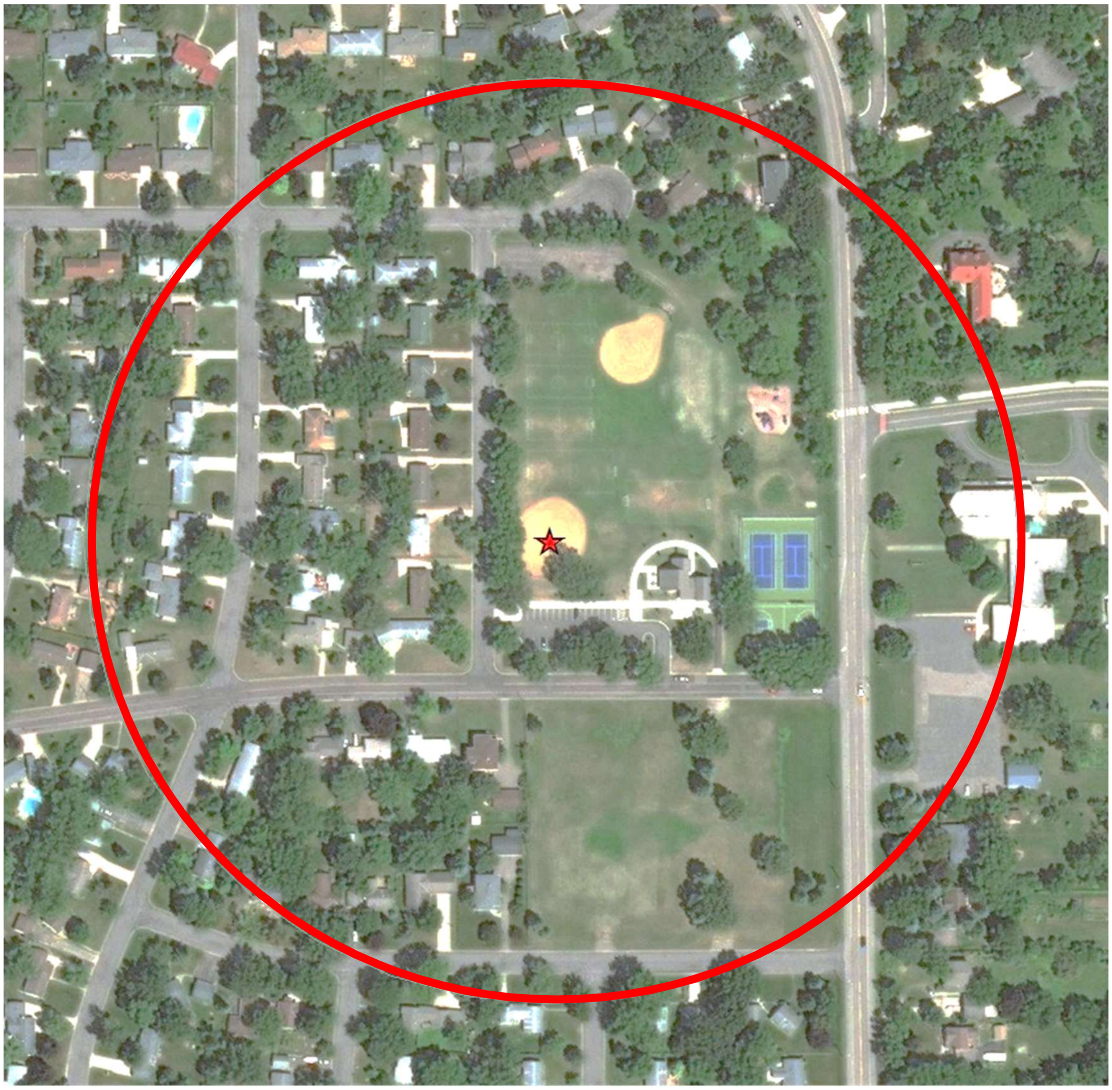

Figure 2.2. Example of urban site, depicted by aerial view of Autumn Grove Park (AG), with the *C. fumipennis* nesting aggregation marked by a star. Tree identification and measurement was carried out in the 200 m radius around the nesting site, indicated by the red circle. Imagery source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Table 2.2. Species of Buprestidae captured by *Cerceris fumipennis* at 19 sites in the summers of 2017 and 2018 in Minnesota, USA. Site JR is excluded due to interruption in sampling. Some beetles were unidentifiable beyond the genus level due to missing heads or other distinguishing features and are also excluded. New records for the state of Minnesota are indicated with bolded font.

Species	**Site**																			**Total**
	AG	**AP**	**BC**	**BP**	**EH**	**FH**	**GE**	**GL**	**MB**	**NE**	**NS**	**SH**	**SP**	**TB**	**TF**	**TL**	**TP**	**WP**	**ZP**	
Acmaeodera pulchella	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	2
Actenodes acornis	0	0	2	0	0	0	0	2	0	0	2	0	0	0	0	0	0	3	0	9
A. simi	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	2
Agrilus anxius	0	0	1	4	0	0	0	0	3	1	0	0	1	2	4	2	7	2	0	27
A. arcuatus	0	3	6	4	11	2	0	18	2	5	0	0	0	5	5	2	31	0	0	94
A. audax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	2
A. bilineatus	2	2	0	8	6	0	0	20	5	3	2	1	8	6	2	0	11	3	0	79
A. carpini	0	0	0	0	0	0	0	0	1	0	0	4	0	0	4	0	1	0	0	10
A. celti	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
A. cliftoni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	2
A. difficilis	0	2	19	1	0	0	3	8	0	0	1	0	0	0	0	1	1	0	0	36
A. egeniformis	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
A. egenus	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
A. granulatus	0	20	1	22	0	12	0	21	3	9	1	2	5	11	4	10	18	10	0	149
A. juglandis	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	4
A. lecontei	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	4
A. obsoletoguttatus	0	0	0	3	1	2	0	3	2	0	0	0	6	2	6	0	7	0	0	32
A. pensus	0	0	0	2	0	0	0	0	1	0	0	0	0	0	1	8	1	0	0	13
A. planipennis	16	4	11	0	4	0	46	4	0	0	0	0	0	0	0	1	0	1	64	151
A. politus	1	9	0	5	2	0	0	6	2	1	0	0	10	0	0	14	6	1	0	57
A. quadriguttatus	0	0	0	8	0	0	0	1	5	0	1	9	0	0	1	4	1	1	0	31

Brachys ovatus	0	0	0	0	0	0	0	0	1	2	0	0	2	0	2	0	1	0	0	8
Buprestis consularis	0	0	4	9	0	0	0	0	10	2	1	0	2	1	16	3	3	4	0	55
B. maculativentris	0	0	0	3	0	0	0	0	7	3	0	1	1	0	2	2	8	0	0	27
B. striata	0	0	1	1	0	0	0	0	5	21	3	0	0	0	7	0	1	4	0	43
Chrysobothris adelpha	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
C. azurea	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	1	0	0	6
C. cribraria	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	2
C. dentipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
C. femorata	1	0	2	3	6	0	0	0	2	0	1	0	0	4	5	0	7	2	0	33
C. orono	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
C. neopusilla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
C. pusilla	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
C. rotundicollis	0	0	0	0	0	0	0	0	1	3	0	1	0	0	2	0	0	2	0	9
C. rugosiceps	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	2
C. sexsignata	23	0	6	2	3	0	0	0	7	3	3	1	1	1	16	3	6	2	1	78
C. viridiceps	0	0	3	0	10	2	0	4	6	0	1	1	3	1	5	1	3	5	0	45
Dicerca asperata	0	0	0	0	0	0	0	0	3	0	0	0	1	0	12	0	2	0	0	18
D. callosa	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
D. caudata	0	0	8	11	2	0	0	1	28	19	5	5	16	20	8	3	112	16	1	255
D. divaricata	0	0	0	3	2	0	0	1	30	18	29	4	1	2	62	2	51	8	0	213
D. lugubris	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	3
D. lurida	0	0	0	0	0	1	0	0	6	0	1	0	0	0	25	0	0	2	0	35
D. tenebrica	0	1	9	26	1	0	0	2	13	34	2	0	0	19	17	1	7	6	0	138
D. tenebrosa	0	1	4	1	0	0	0	0	9	10	4	0	0	0	1	2	2	0	0	34
Eupristocerus cogitans	0	0	0	5	0	0	0	0	6	1	0	0	1	0	0	16	16	0	0	45
Phaenops aeneola	0	0	0	0	0	0	0	0	3	2	2	0	0	0	2	0	0	0	0	9
Poecilonota cyanipes	0	2	2	11	0	0	0	5	4	4	1	0	1	2	1	5	20	3	0	61
P. ferrea	0	0	0	0	0	0	0	0	3	9	0	0	0	0	1	0	1	1	0	15

P. thureura	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Spectralia gracilipes	1	0	1	0	4	1	0	2	3	0	0	0	0	3	0	0	0	6	0	21
Total	44	47	82	133	56	22	52	98	174	156	61	30	59	80	217	80	327	87	66	1871

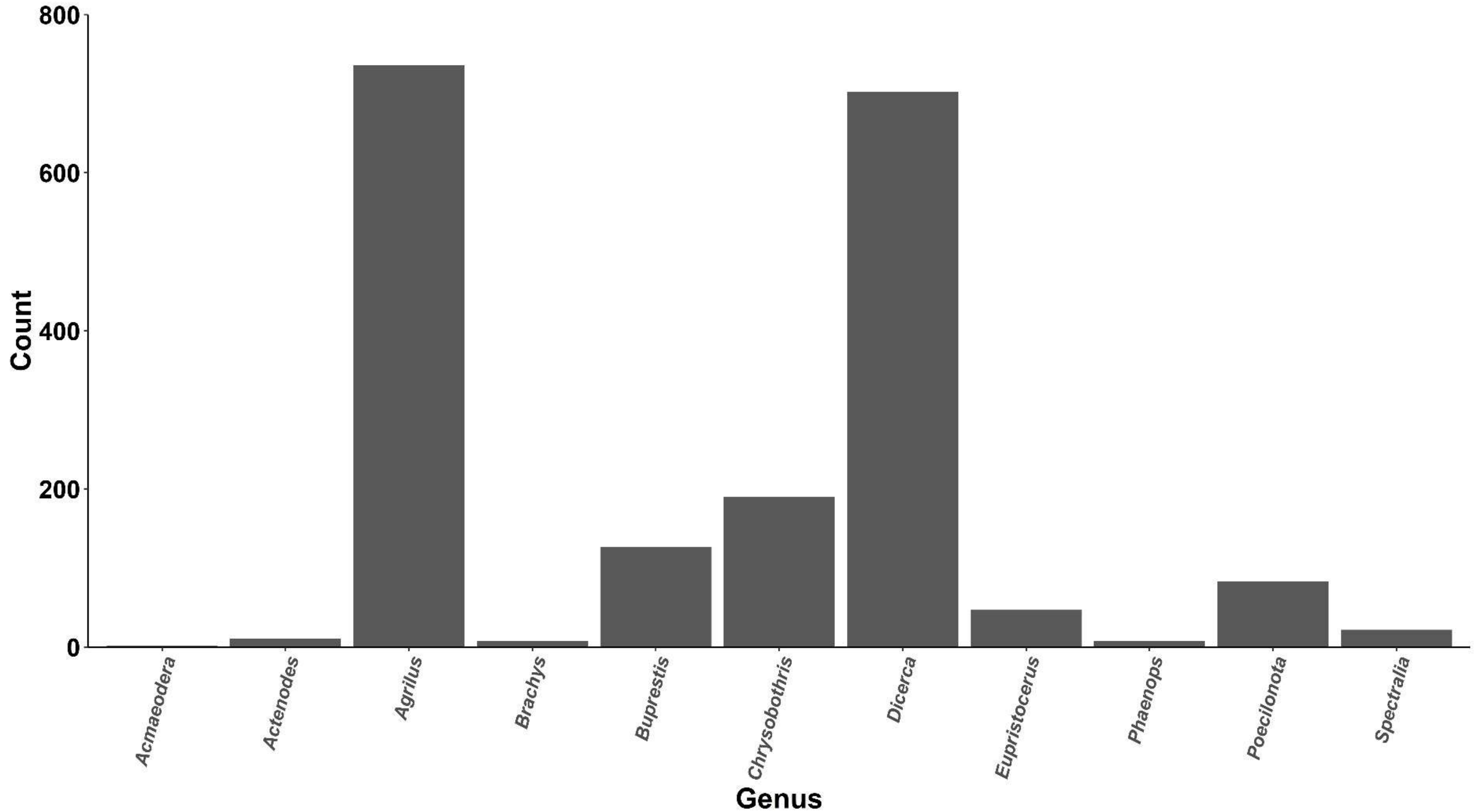

Figure 2.3. Buprestids by genus collected at 20 nesting sites of *Cerceris fumipennis* from 2015 – 2018 in Minnesota, USA**.**

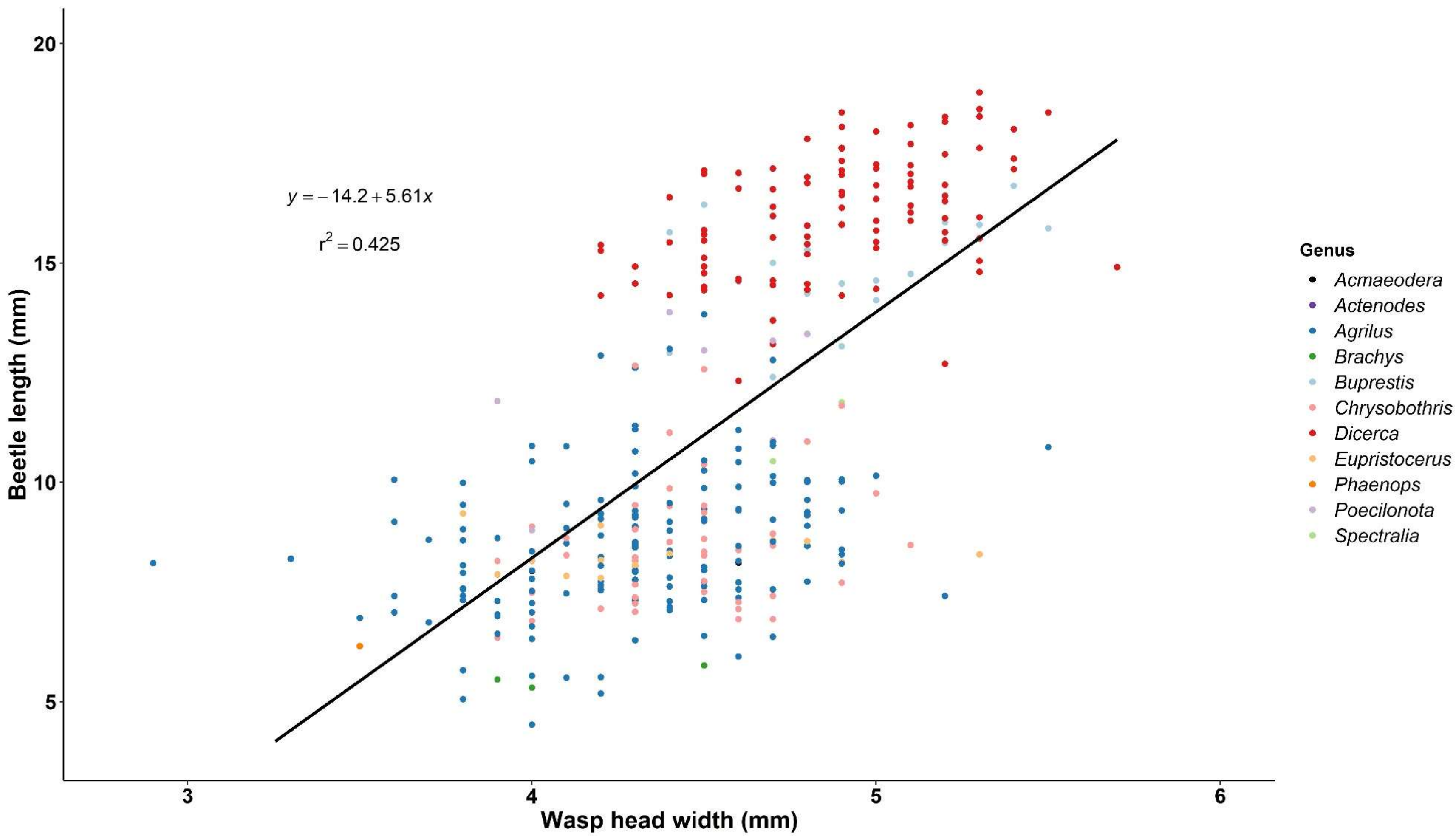

Figure 2.4. The relationship between the head width of individual *Cerceris fumipennis* wasps (n = 345) and length of beetle prey collected from 10 sites during July 2017 in Minnesota, USA.

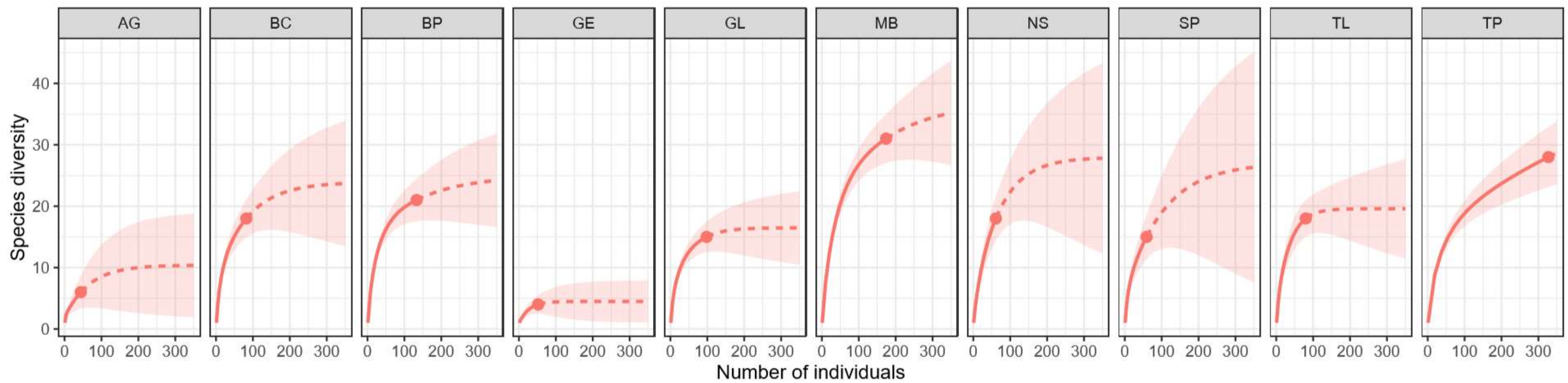

Figure 2.5. Extrapolated species richness at the 10 *Cerceris fumipennis* nesting sites where we looked for relationships between buprestid species richness and site level characteristics. The solid line represents a rarefaction curve based on the sample size collected, while the dotted line represents extrapolated species richness up to a sample size of 350 individuals. Red bands represent 95% confidence intervals for species richness predictions. Models in table 2.3 were based on comparisons at 88 individuals.

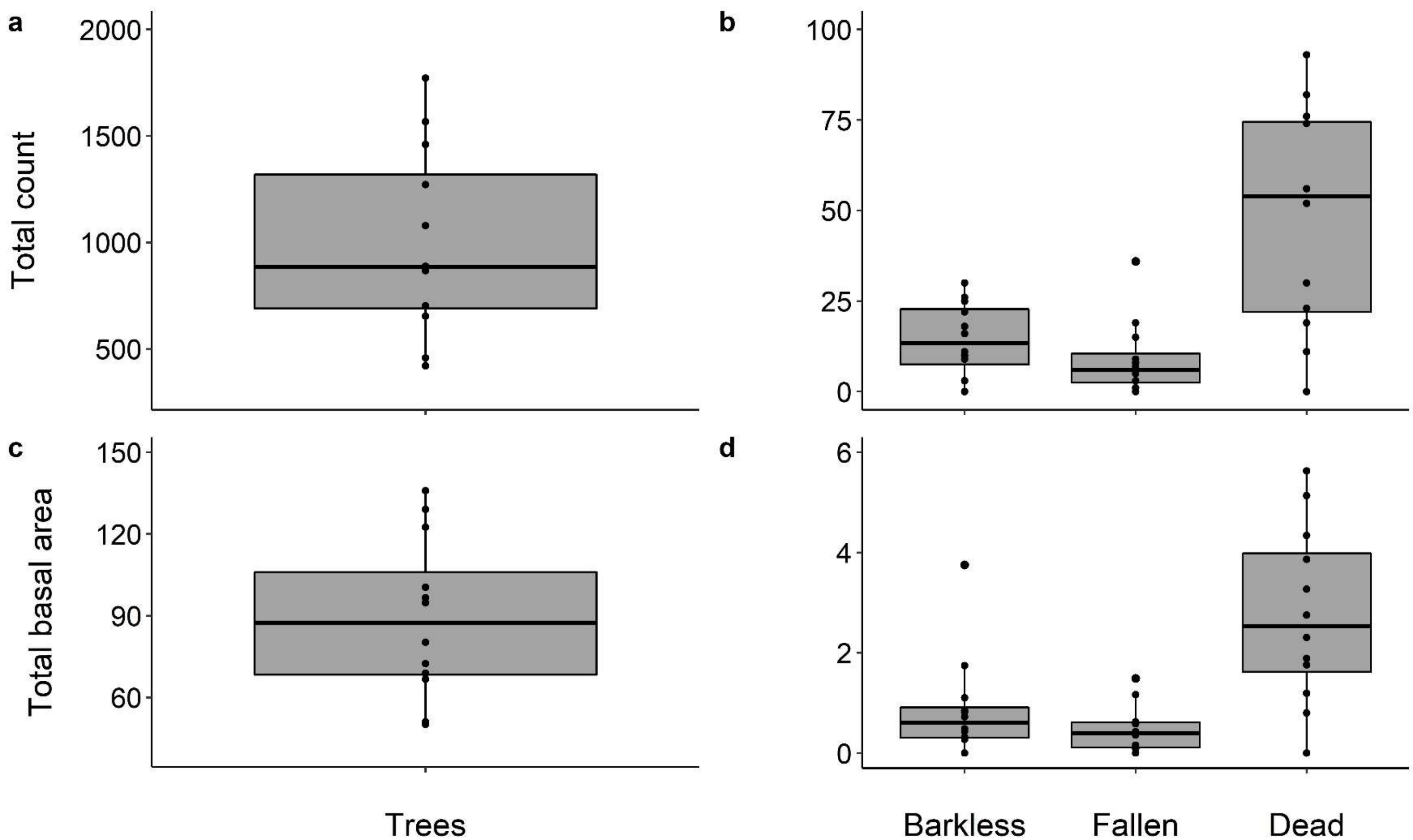

Figure 2.6. Total number of trees (a), total number of barkless, fallen, and dead trees (b), total basal area (BA) in m^2 of trees (c) and total BA of barkless, fallen, and dead trees (d) within 200 m of a *Cerceris fumipennis* nesting aggregation at 12 Minnesota sites in 2018.

Table 2.3. Minimum, maximum, median, and mean intercept and slope estimates for relationships between adjusted species richness (species richness when sample number is extrapolated or interpolated to 88 individuals) of buprestids collected from *C. fumipennis* nesting aggregations and site characteristics within 200 m of each nesting aggregation at 10 sites, central MN, USA, 2017-2018. For example, to estimate number of species at a site with x = 540 trees, y = 6.41 + 0.0104 * 540 = 12, using the mean intercept and slope values listed.

	Intercept				Slope			
Explanatory variable	**Min**	**Mean**	**Median**	**Max**	**Min**	**Mean**	**Median**	**Max**
Total trees	3.79	6.41	6.42	9.14	0.0076	0.0104	0.0105	0.0131
Total BA trees (m^2)	4.43	8.24	8.21	11.88	0.0484	0.0931	0.0931	0.1417
Total dead trees	7.41	8.65	8.66	9.96	0.0842	0.1078	0.1079	0.1312
Total BA dead trees (m^2)	10.15	12.15	12.16	14.30	1.149	2.031	2.024	2.866
Total fallen trees	11.11	12.18	12.17	13.20	0.0902	0.1591	0.1584	0.2375
Total BA fallen trees (m^2)	11.12	12.15	12.13	13.32	1.632	3.108	3.102	4.498
Total barkless trees	8.97	9.99	9.99	11.06	0.1972	0.2646	0.2655	0.3255
Total BA barkless trees (m^2)	11.70	12.62	12.61	13.55	0.7362	1.2538	1.2492	1.7699
Tree genus richness	16.45	21.68	21.73	27.78	-0.6742	-0.3854	-0.3865	-0.1365
Average number of nests	11.10	12.25	12.24	13.27	0.0169	0.0260	0.0260	0.0347

Table 2.4. Positive relationships between buprestid species collected at *Cerceris fumipennis* nesting aggregations and surrounding tree genera in MN, USA. The middle column, tree genera with positive associations, lists genera of trees that are statistically positively associated with the insect species listed in that row, based on empirical sampling at 12 sites ($p < 0.01$). The final column lists known host associations (larval and adult) from the scientific literature. Positively associated tree genera that are also known hosts are bolded. An asterisk next to a genus in the middle column indicates that genus is positively correlated with one of the known host genera (from the final column) across our sites.

Buprestid species	Positively associated tree genera	Known host genera
Agrilus anxius	*Picea**, *Quercus**	*Betula, Populus*
Agrilus arcuatus	*Picea, Prunus**, ***Quercus***, *Sorbus**	*Carya, Fagus, Juglans, Quercus*
Agrilus bilineatus	*Abies, Picea, Pinus, Prunus**, ***Quercus***, *Sorbus**	*Quercus*
Agrilus difficilis	*Celtis**, *Fraxinus**, ***Gleditsia***, *Rhamnus*	*Gleditsia*
Agrilus granulatus liragus	*Abies, Catalpa, Picea, Pinus, Quercus, Salix**	*Populus*
Agrilus obsoletoguttatus	*Abies, Picea, Pinus*, ***Quercus***	*Carpinus, Carya, Gleditsia, Ostrya, Quercus*
Agrilus planipennis	*Celtis*, ***Fraxinus,*** *Gleditsia**, *Juglans, Morus, Ostrya, Sorbus, Syringa, Tilia*	*Fraxinus*
Agrilus politus	*Abies**, ***Picea***, *Quercus**, ***Salix***	*Acer, Alnus, Picea, Salix, Thuja*
Agrilus quadriguttatus	*Acer, Catalpa, Pinus*, ***Populus***, *Prunus, Thuja, Ulmus*	*Alnus, Populus, Salix*

Buprestis consularis	*Acer*, Catalpa*, Juniperus*,* ***Pinus,*** *Rhamnus, Robinia, Thuja*	*Larix, Picea, Pinus*
Buprestis maculativentris	***Picea****, Quercus, Robinia, Thuja*	*Larix, Picea, Pinus*
Chrysobothris femorata	*Picea**	*Acer, Amelanchier, Carpinus, Celtis, Crataegus, Fraxinus, Juglans, Larix, Malus, Populus, Prunus, Quercus, Sorbus, Tilia, Ulmus*
Chrysobothris sexsignata	***Juglans****, Morus, Tilia**	*Acer, Amelanchier, Betula, Carya, Celtis, Fagus, Fraxinus, Gleditsia, Juglans, Larix, Picea, Pinus, Quercus, Sorbus, Tsuga, Ulmus*
Chrysobothris viridiceps	***Quercus****, Robinia**	*Acer, Carya, Pinus, Quercus, Ulmus*
Dicerca caudata	*Picea*, Pinus, Quercus*, Robinia*	*Alnus, Betula, Crataegus, Larix, Prunus*
Dicerca divaricata	***Betula****, Juglans*, Juniperus*, Picea*,* ***Pinus****,* ***Quercus****, Robinia*, Salix*, Thuja**	*Abies, Acer, Betula, Fagus, Fraxinus, Larix, Ostrya, Pinus, Populus, Prunus, Quercus, Ulmus*
Dicerca tenebrica	*Acer*, Catalpa*, Juniperus*, Picea,* ***Pinus****, Rhamnus, Robinia*	*Larix, Pinus, Populus*
Dicerca tenebrosa	*Fraxinus, Juglans, Juniperus*, Rhamnus, Robinia, Thuja*	*Abies, Picea, Pinus, Pseudotsuga*
Eupristocerus cogitans	*Picea*, Quercus, Salix*	*Alnus, Betula*
Poecilonota cyanipes	*Catalpa, Picea, Quercus*, Pinus*	*Populus, Robinia, Salix*

Chapter 3

Individual outcomes of the "Wasp Watchers" citizen science program in Minnesota

Summary

Citizen science programs have been growing in popularity since the early 1990s. These programs are often assumed to provide positive outcomes such as increases in content knowledge, scientific literacy, and confidence in addressing environmental problems (environmental self-efficacy) among individual volunteers. We administered a survey to participants in a citizen science group known as Wasp Watchers, a program designed to utilize the natural behavior of the native ground-nesting hunting wasp *Cerceris fumipennis* to detect the invasive emerald ash borer (*Agrilus planipennis*) and survey buprestid communities. We sought to find whether there was a link between total hours of program participation, self-reported knowledge, and factors that may influence pro-environmental behavior such as interest in learning, likelihood of advocacy, and environmental self-efficacy. Volunteers reported higher self-efficacy in association with higher invasive species knowledge. We found no relationship between total hours spent volunteering in the Wasp Watchers program and self-reported interest in learning, advocacy, self-efficacy, or pro-environmental behaviors. Volunteers reported additional outcomes such as increased community connection, opportunities to reach out to family and friends, and increased knowledge about native wasps and emerald ash borer. This work has implications for citizen science program design, which may benefit from setting individual outcomes as explicit goals.

Introduction

Modern day amateur naturalists have been keeping environmental records since at least the late 19th century. In the United States, early environmental volunteering often involved large monitoring projects, such as the National Audubon Society's Christmas Bird Count. This project began in 1900 and enlisted citizens to record information about bird populations (Cohn 2008). Since the late 1990s, the number of citizen science programs has increased considerably, diversifying beyond large-scale monitoring and often focusing on specific scientific or policy questions (Bonney et al. 2016). Stepenuck and Green (2015) synthesized peer-reviewed journal articles about citizen science and found that 89% of 436 articles reviewed have been published since the year 2000.

Several factors are responsible for this increase of interest in citizen science: technology, granting agencies, and a movement to democratize science education. Technology, such as the internet and the proliferation of smart devices and computers, makes data collection more accessible. The National Science Foundation (NSF), along with other funding agencies, stipulates science education as a goal for funded projects (Silvertown 2009; Bonney et al. 2016). More broadly, a movement to democratize scientific education and update it from a one-way "deficit" model to a participatory partnership with scientists has increased conversations about how best to involve the public in environmental decision making (Irwin 2006; Davies 2008; Shirk et al. 2012; Bonney et al. 2016). Policy makers commonly assume citizen science is a useful tool to both educate the public and engage individuals in environmental policy discussions, but few studies have examined the evidence for these assumptions (Stepenuck and Green

2015). An important emerging challenge is how to identify and measure individual outcomes of citizen science programs.

Outcomes attributed to citizen science programs include knowledge gain, increase in scientific literacy, and an increase in environmentally responsible behavior. The most commonly investigated outcome is knowledge gain, a broad category that includes general ecology knowledge, knowledge specific to a particular field, and knowledge about local natural resource management. Most studies report positive knowledge gains as an outcome of citizen science participation (Brossard et al. 2005; Evans et al. 2005; Kountoupes and Oberhauser 2008; Cornwell and Campbell 2011; Jordan et al. 2011). Another commonly investigated outcome of citizen science programs that shares traits with knowledge gain is "scientific literacy," or awareness of the scientific process. Studies focusing on scientific literacy attempt to measure whether participation in citizen science programs increases public understanding of science, including a shift in positive attitudes towards science and an increased understanding of experimental design techniques (Laugksch 2000; Trumbull et al. 2000; Brossard et al. 2005; Crall et al. 2012). However, these studies do not always detect a change in scientific literacy, as people often enter programs with specific interests in mind and not a general interest in learning about science, and most are likely to show improvement in context-specific knowledge rather than general knowledge about the scientific method (Cronje et al. 2011; Crall et al. 2012). An increase in positive attitude toward science has sometimes been noted as a result of citizen science program participation (Price and Lee 2013), but more often no change is detected (Trumbull et al. 2000; Brossard et al. 2005).

Beyond a change in knowledge and attitudes about science, several researchers have investigated changes in attitudes and beliefs towards the environment, conservation, and commitment to engage in environmental behaviors. Again, these studies have not always detected a change in behaviors, possibly because those willing to volunteer in citizen science programs already express high levels of concern for environmental conservation before participation (Brossard et al. 2005). Jordan et al. (2011) asked volunteers about their behavior before and after taking part in an invasive species training program, as one example. While researchers did note some behavioral change, they reported the nature of this change as mostly passive, such as noticing more invasive plants. Jordan et al. (2011) hypothesized that it may be the feeling of a lack of control that leads participants to believe taking action is futile, especially with a diffuse and overwhelming problem such as invasive species spread. As such, they called for citizen science programs to consciously aim at dismantling these "motivational barriers" to environmental action, identifying "self-efficacy" as an important factor in motivation for environmental action.

Self-efficacy, also called "locus of control," is related to confidence in one's ability to address problems and is positively correlated with pro-environmental behaviors (Bandura 1977; Hines et al. 1987; Kollmuss and Agyeman 2002; Jordan et al. 2011). Hines et al. (1987) performed a meta-analysis that identified knowledge of issues, knowledge of action strategies, locus of control, attitudes, verbal commitment, and an individual's sense of responsibility as important predictors of environmentally responsible behavior. Kollmuss and Agyeman (2002) combined many of these factors into a complex they call "pro-environmental consciousness." Participation in a citizen science program is one of many external factors that may, in turn, influence knowledge, self-efficacy, advocacy, and ultimately pro-environmental behavior.

Several studies have examined the question of environmental self-efficacy as influenced by citizen science programs. Johnson et al. (2014) found a high level of concern for environmental issues served as a strong motivation for participation in citizen science programs, for example. The authors also found evidence of volunteers acting as “advocates,” i.e. reaching out to family and friends and asking them to volunteer, thus creating a growing social network of environmental concern. Johnson et al. (2014) described these outcomes as evidence for increased self-efficacy in participants, as participants became “opinion leaders” in their communities with the confidence to share their knowledge with others. Dresner et al. (2015) took a slightly different approach in their attempt to measure environmental self-efficacy. The authors acknowledged the importance of social relationships, but additionally focused on a construct adapted from previous authors called “environmental literacy,” which incorporates environmental knowledge, attitude toward the environment, behavioral strategies, and effective environmental decision making into a single concept (Hungerford and Volk 1990; Roth 1992; Hollweg et al. 2011). While not a direct measure of self-efficacy, the authors consider environmental literacy a measure of confidence and empowerment that indicates self-efficacy.

Gaps remain in our knowledge of individual outcomes from participation in citizen science. Most work on individual outcomes of citizen science programs focuses on changes in content knowledge, leaving a need to explore outcomes related to the citizen scientist’s role and voice in decision making (Stepenuck and Green 2015).

Additionally, apart from the studies cited here, few studies have examined self-efficacy, despite its importance in driving behavioral change and its linkage to community resilience (Ballard and Belsky 2010). While not always an explicit goal of citizen science programs, the educational materials provided to volunteers and the social ties they create with both organizers and other volunteers may result in increased expertise and confidence in addressing environmental problems.

My work focuses on a citizen science program known as Wasp Watchers. The "Wasp Watchers" program is a citizen science project organized through the University of Minnesota Extension and the Minnesota Department of Agriculture and initiated in 2015. In Wasp Watchers, volunteers utilize a native non-stinging hunting wasp, *Cerceris fumipennis*, to track the spread of the invasive emerald ash borer beetle (Buprestidae: *Agrilus planipennis*), as well as monitor for new non-native beetles in the Buprestid family (http://waspwatchers.umn.edu/). While "biosurveillance" is the stated goal of the program, there may be additional benefits to volunteers. In Wasp Watchers, participants take an active role in detecting the emerald ash borer, an invasive beetle, in their communities, rather than simply receiving education on identifying invasive species. The practical nature of the program may be a strength that combats the potential feelings of passivity or insignificance in the face of significant environmental problems noted by Jordan et al. (2011). Social outcomes similar to those observed by Johnson et al. (2014) and Dresner et al. (2015) are expected in Wasp Watchers, as volunteers often bring along family and friends when they volunteer.

This study addresses the change in individual characteristics concerning invasive species issues resulting from participation in this citizen science program, focusing on self-efficacy and related concepts such as interest in learning and advocacy. We hypothesize that these factors, analogous to the "environmental literacy" and "pro-environmental consciousness" as conceptualized in the literature, will increase due to program participation and will influence the likelihood of volunteers participating in pro-environmental behaviors. This study will aid in the development of future citizen science projects and identify whether commensurate citizen science projects are effective tools to engage communities in environmental decision making.

Methods

Wasp Watchers program participation

To participate in the Wasp Watchers program, volunteers are encouraged to attend a one to two hour training session at a local baseball diamond. *Cerceris fumipennis* wasps preferentially nest in hard packed, sandy locations such as dirt parking lots, trail edges, and baseball diamonds (Evans 1971; Nalepa et al. 2012). Once there, volunteers learn how to identify wasp nests and intercept incoming wasps to collect their prey. Volunteers receive equipment necessary to monitor local *C. fumipennis* nesting aggregations on their own time. Volunteers either scout for new nesting aggregations or collect buprestid beetles from known nesting aggregations. Collected beetles are placed individually into vials labeled with the site and date. Additional optional training experiences, such as an educational presentation about the emerald ash borer or a talk from experts about emerald ash borer control strategies, have also been available to volunteers in the past.

Survey design and administration

We developed a survey to administer to Wasp Watchers volunteers based on past literature. We measured three constructs of interest related to engagement in citizen science: interest in learning, advocacy and self-efficacy. The first construct measured was “interest in learning,” analogous to change in knowledge based on an experiential education framework measured by other citizen science outcome studies (Joplin 1981; Brossard et al. 2005; Crall et al. 2012). Experiential learning has been defined as a process giving participants or students primary responsibility for taking action to solve a problem, with learning facilitated through reflection on that experience (Joplin 1981; Tuss 1996). Citizen science programs are modeled on a process of real-world engagement with science and therefore represent a pathway for experiential learning (Tuss 1996; Bonney et al. 2009).

“Advocacy” and “environmental self-efficacy” were measured based on the three-step process proposed by Johnson et al. (2014) and adapted from Katz (1957), in which individuals motivated to gain knowledge about environmental topics (“environmental opinion leaders”) (1) seek volunteer opportunities, (2) gain self-efficacy through expertise gained by working with scientists, and then (3) serve as influential educators in their own social networks. The scale created for environmental self-efficacy was modeled after an environmental self-efficacy measurement tool developed through the DEVISE project from the Lab of Ornithology at Cornell, after the identification of “environmental self-efficacy” as a valid construct and a measureable project outcome (Phillips et al. 2014; Bonney et al. 2016). We asked participants about pro-environmental behaviors, again specifically in the context of invasive species action. Interest in learning and perceived self-efficacy ultimately correspond to factors predicted to influence pro-environmental behavior, defining ‘pro-environmental behavior’ as conscious activity taken to minimize negative impact on the natural world (Stern 2000; Kollmuss and Agyeman 2002; Johnson et al. 2014).

The questionnaire contained six sections: one inquiring about volunteering and training experience, three corresponding to the constructs measured (interest in learning, advocacy, and environmental self-efficacy), one asking about environmentally responsible behaviors, and a demographic section including questions on age, gender, and employment for sample description purposes. All scales were assessed with researcher developed Likert-type items (Likert 1932; Maurer and Pierce 1998). Volunteers self-reported their interest in learning, likelihood of advocacy, and belief towards ability to address environmental concerns, focusing on belief and behavioral change that has occurred because of program participation. Interest in learning was measured on a 5-point continuum scale ranging from much less interested (1) to much more interested (5). Advocacy likelihood was measured on a 5-point continuum scale ranging from much less likely (1) to much more likely (5). To measure environmental self-efficacy, respondents were asked about the extent to which they agreed or disagreed with a series of statements about confidence managing invasive species, with responses ranging from disagree (1) to agree (4). The advocacy and self-efficacy scales additionally included a N/A response, as some items on these scales referenced property ownership or neighborhood associations that would not apply to all respondents.

Institutional Review Board (IRB) approval for research involving human subjects was sought, but deemed unnecessary by the review board under current regulations. We administered the 22 question survey to Minnesota Wasp Watchers volunteers in January

2019 (n=114). Volunteers were identified through an email list provided to the program coordinator, and emailed with a request to complete the questionnaire anonymously and confidentially. Individuals who did not initially respond were sent a reminder two days later, and those who still did not respond were sent an additional reminder one week from the initial notification date. There were no incentives offered for completing the questionnaire. We conducted interviews with three people with varying levels of involvement in the program to refine questions and question wording (due to the small population size targeted by this survey, a full pilot test with Wasp Watchers volunteers was not plausible). Error was additionally minimized through writing items in compliance with best practices as outlined by Haladyna and Rodriguez (2013) and Dillman et al. (2014). The entire questionnaire is provided in the appendix (3.1).

Analysis

All data were analyzed using the Statistical Package for the Social Sciences (IBM SPSS version 25, 2017). Reliability and item analyses were conducted on the scales corresponding to the three constructs previously outlined: interest in learning, advocacy, and environmental self-efficacy. Discrimination values were computed for each item, and Cronbach's alpha used as a measure of internal consistency for each overall scale. Discrimination values were positive and relatively high for all items, indicating all contribute to the constructs of interest. All scales had a high Cronbach's alpha ($> .70$), indicating a high score reliability and consistency in item measurement. Item responses were averaged to form a composite score for each scale. Descriptions and summary statistics for items and scales are included (Table 3.1).

To determine whether these measures varied based on volunteer characteristics, we created variables for "volunteering experience" and "reported knowledge." Volunteering experience was represented by a question with four options (less than 1 hour volunteering, 1-4 hours, 5-10 hours, and over 10 hours). Respondents in the first three categories (<10 hours of volunteering activities) were placed into a "low" experience group (n = 26) and respondents in the second two categories (>10 hours volunteering) were placed into a "high" experience group (n = 24). To measure reported knowledge, participants were asked to evaluate their level of knowledge about aspects of the Wasp Watchers system on a 4 point scale ranging from "not at all knowledgeable" (1) to "very knowledgeable" (4). Reliability and item analysis were performed on this scale (α = .80) and items were averaged to produce a single "reported knowledge" measure. We used a median split on this score to place respondents in "low" (n = 27) and "high" (n = 23) reported knowledge groups. Independent sample t-tests were then performed to discover potential relationships between volunteering experience, reported knowledge, and interest in learning, advocacy, and environmental self-efficacy scores.

To determine whether pro-environmental behaviors differed based on volunteer experience and knowledge, we performed a series of Chi-square contingency tests evaluating associations between experience level (low/high), reported knowledge (low/high), and reported participation in five invasive-species related environmental behaviors (yes/no). Of the environmental behavior questions, two that asked participants about action taken on their property had a high number of N/A responses. Expected frequencies for cells in tests including these two categories consistently fell under five, violating assumptions for Chi-square tests, so these two questions were excluded from analysis.

Results

A total of 115 questionnaires were emailed to Wasp Watchers volunteers. The overall response rate was 47% ($N = 54$). We determined a sample of 54 from the 114 email addresses on file would afford a 5% sampling error and 68% confidence interval. One respondent reported being under 18 years old, so their response was removed. After removing additional cases with incomplete responses, the sample size analyzed was $N = 50$. The age of respondents varied from 18 to 77, with an average between 48 and 57 years old. A majority of respondents were 48 years old or older (76%), female (60%), with at least a bachelor's degree (90%), and had previously worked in a science or natural resource field (59%). Most respondents (65%) reported volunteering for at least one other citizen science program in addition to Wasp Watchers in the previous year, and 10% reported volunteering for three or more programs. The majority of respondents (78%) reported volunteering for five or more hours in the Wasp Watchers program.

Participants with "high" knowledge reported significantly higher environmental self efficacy scores than participants with "low" knowledge (M=3.25, SD = 0.58 vs M=2.90, SD = 0.60, respectively, $t = 2.06$, df = 48, $p = 0.045$, Table 3.2). There were no statistically significant differences in "interest in learning" or "advocacy" based on experience level or reported knowledge (all $p > 0.05$, Table 3.2). Similarly, there was no difference in "environmental self-efficacy" depending on experience level ($p = .681$). There were no significant differences in the frequency of environmental behaviors based on experience level or reported knowledge (all $p > 0.05$).

Discussion

Increased knowledge about either the scientific process or a specific environmental system is a well-known individual outcome of citizen science projects (Evans et al. 2005; Jordan et al. 2011; Stepenuck and Green 2015). We noted higher environmental self-efficacy associated with higher reported levels of knowledge about invasive species issues, which suggests that participation in Wasp Watchers is likely to increase participants' knowledge about invasive species issues, and by extension, their confidence when it comes to taking action on invasive species issues. In turn, increased self-efficacy is linked to positive environmental action (Hines et al. 1987; Kollmuss and Agyeman 2002).

The lack of change in learning and advocacy among participants in Wasp Watchers may be explained by limitations in our study design. The "low" experience group contained all individuals reporting under 10 hours of participation in volunteering activities, but most had several hours of experience. It may be that categorical delineation was not sufficiently fine-tuned to capture any difference between different gradients of experience. A true "low" group would likely be restricted to those who volunteered for just an hour or two and did not regularly participate in the program. It is possible that these individuals were not as motivated as more dedicated volunteers in responding to the survey, and thus represent non-response bias. A larger sample size with a wider range of volunteer hours, or a before and after study design, would likely be necessary to truly draw conclusions about individual outcomes from the Wasp Watchers program.

The lack of change associated with experience may also be explained by the nature of our study population. Wasp Watchers volunteers in many cases already met the definition of “environmental opinion leaders” (Dalrymple et al. 2013; Johnson et al. 2014) and so were likely already highly motivated and empowered to act as environmental advocates. Over half of respondents currently work or had previously worked in a science or natural resource field, and over half had recently volunteered for one or more other citizen science programs in addition to Wasp Watchers. This pattern indicated an overall high level of engagement with “scientific” issues in their communities. We asked respondents about *change* in interest in learning, advocacy, and self-efficacy. It is likely that these respondents were highly motivated in the first place and did not necessarily experience much change as a result of Wasp Watchers participation. One respondent noted the potential for misleading conclusions as a concern in the open-ended response section at the end of the survey, writing; “I was already very involved in invasive species control activities through my work so Wasp Watchers did not influence my interest in that area. Answering questions related to the impact of Wasp Watchers on my attitudes towards this might give the impression that I would be a disinterested person, which is not the case.”

In addition to the constructs measured, comments from volunteers revealed additional program motivations and outcomes. Many of these motivations reflected environmental values; participants reported that they liked “being able to assist in controlling and managing emerald ash borer,” and the “very tangible results.” Several commenters mentioned liking that program activities are “valuable to conservation efforts,” and several more reported a sense of civic service, such as one person who liked the “feeling I’m making an important contribution to my community.” Of the 45 people who left comments on what they liked about the program, 16 (36%) mentioned learning or an increase of knowledge, either about native wasps or about emerald ash borer, as a primary positive outcome of the program, such as the person who mentioned they enjoyed “getting outdoors and learning about the way of nature – first hand.”

There was also evidence that Wasp Watchers volunteers already act as advocates in their communities. Of all survey respondents, 39% reported taking a friend or family member along to volunteer, 90% reported speaking with family members about the Wasp Watchers program at least once, and 94% reported speaking with friends about the program. Additionally, 39% reported posting about Wasp Watchers on social media at least once. One participant commented that the thing they most enjoyed about their experience was “spreading information to others.” Thus, volunteers did report positive experiences related to the constructs we sought to measure.

While we did not see evidence for many of the self-reported outcomes of interest as measured by our survey, we do not conclude that the Wasp Watchers program has not been effective in achieving its goals. Over the past four years, Wasp Watchers participants collected hundreds of buprestid beetles that led to an increased understanding of jewel beetle distribution in the state of Minnesota (Chapters 1 and 2) and the detection of emerald ash borer in a new Minnesota county (Goodhue). Large social networks capable of sharing information about species distributions are important when it comes to invasive species management. Citizen science programs can meet such goals as they bring together large numbers of people into geographically diffuse networks effective for detecting and monitoring invasive species (Simpson et al. 2009; Gallo and Waitt 2011; Looney et al. 2016). Invasive species tend to be introduced sporadically and spread rapidly, making their detections, identification, and management challenging for specialists and non-specialists alike. In this regard, the program has achieved the kind of broad-scale urban environmental monitoring of which citizen science programs are capable, but that would be difficult to achieve through traditional approaches (Cooper et al. 2007).

We cannot draw any conclusions about the impact of participation itself, as this was not a before-and-after participation survey. Future work could include a similar survey administered to potential volunteers before and after program participation to truly link outcomes to program participation. If further individual outcomes are desired by program managers, literature suggests these outcomes should be deliberately designated as goals and integrated into the design of a participatory science program (Bonney et al. 2016). Whether or not Wasp Watchers results in increases in interest in learning, advocacy, or self-efficacy, volunteer comments make it clear that participation in the program has been a positive experience and a way to engage meaningfully in their communities.

Table 3.1. Means, standard deviations, and reliabilities for reported individual outcomes from a 2019 survey issued to Wasp Watchers volunteers

Dimension	α	Item	M	SD
Interest in learning[1]	0.88	Volunteering for other citizen science projects	3.98	0.85
		Reading about emerald ash borer	3.77	0.76
		Attending an informational meeting about invasive plants	3.75	0.76
		Reading about environmental issues	3.69	0.78
		Reading about invasive plants	3.67	0.81
		Reading about other invasive insects	3.63	0.79
		Attending an informational meeting about emerald ash borer	3.56	0.87
		Attending an informational meeting about other invasive insects	3.56	0.80
Advocacy likelihood[2]	0.88	Speaking with a friend about emerald ash borer	4.10	0.71
		Speaking with a family member about emerald ash borer	4.05	0.75
		Inviting a friend to volunteer for a citizen science program	3.93	0.83
		Inviting a family member to volunteer for a citizen science program	3.90	0.84
		Posting information about emerald ash borer on social media	3.58	0.98
		Speaking with a community group about emerald ash borer	3.53	0.75
		Speaking with a representative from your community about its emerald ash borer management plan	3.48	0.78
		Speaking with your neighborhood association about emerald ash borer	3.45	0.71
Environmental self-efficacy[3]	0.81	I know what actions to take to benefit native species	3.61	0.68
		I am capable of controlling invasive plants on my property	3.29	0.84
		I can help find solutions to invasive species issues	3.18	0.83
		I feel confident in my ability to manage emerald ash borer on my property	3.11	0.98
		I am able to influence management of other invasive insects on my property	3.03	0.85
		I feel confident in my ability to help manage emerald ash borer in my community	2.97	0.85
		I am capable of controlling invasive plants in my community	2.84	0.92
		I am able to influence management of other invasive insects in my community	2.76	0.85

[1] Item measured on a scale of 1-5 where 1 = much less interested and 5 = much more interested
[2] Item measured on a scale of 1-5 where 1 = much less likely and 5 = much more likely
[3] Item measured on a scale of 1-4 where 1 = disagree and 4 = agree

Table 3.2. Differences in Wasp Watchers volunteers' reported individual outcomes based on (A) amount of volunteering experience[1] and (B) reported knowledge[2]

A.

Response	Mean[1] Low Experience (n= 26)	High Experience (n=24)	t-value	p-value
Interest in learning	3.79	3.66	0.79	0.44
Advocacy	3.74	3.85	0.66	0.51
Environmental self-efficacy	3.03	3.10	0.41	0.68

B.

Response	Mean[2] Low Knowledge (n= 27)	High Knowledge (n=23)	t-value	p-value
Interest in learning	3.78	3.66	0.68	0.50
Advocacy	3.86	3.71	0.85	0.40
Environmental self-efficacy	2.90	3.25	2.06	0.045*

Significance: < 0.05 (*)

[1]Measured by total hours spent on Wasp Watcher volunteer activities where ≤10 hours = low and >10 hours = high
[2]Five items measured on a scale of 1-4 where 1 = not at all knowledgeable and 4 = very knowledgeable. Items averaged to produce a single "knowledge" measure, then divided by median split

Thesis Conclusions

Chapter 1

1) **There are many collected but previously unpublished buprestid species and host records in the state of Minnesota.** A total of 30 buprestid species in the University of Minnesota insect collection (UMSP) were previously unreported in the state. In addition, when available we report the plant on which adults were collected, although adult host information may not be definitive.

2) **Sampling at *Cerceris fumipennis* nesting aggregations is an effective tool for detecting previously uncollected species in Minnesota.** A total of 12 buprestid species were collected for the first time at *C. fumipennis* nesting aggregations. These species have either been present in the state but undetected by prior sampling techniques, recently introduced, or have undergone a range expansion.

Chapter 2

1) **Urban forests contain a large number and variety of buprestid beetle species, and they are efficiently foraged by *C. fumipennis.*** A total of 51 species were collected from 20 nesting aggregations of *C. fumipennis*, with *Agrilus* and *Dicerca* as the most commonly collected species. Wasps at our sites were large enough to forage for beetles of all genera known to be collected by *C. fumipennis*.

2) **Species richness of buprestid beetles at urban sites varies based on total number of trees present and amount of dead wood present within 200 m, among other factors.** Species richness rarefaction curves varied considerably from site to site. Sites with more total dead trees were associated with higher species richness.

3) **Sites with large numbers of emerald ash borer appeared to have lower species richness.** This pattern suggests emerald ash borer infestations may have a negative impact on buprestid biodiversity, or *C. fumipennis* may preferentially return to trees infested by EAB.
4) **Buprestid species collected by *C. fumipennis* reflect the tree canopy in a 200 m radius around the nesting aggregation.** Out of 20 species examined, 65% were positively correlated with at least one known host genera. Additional correlations may be spurious, or may represent previously unknown host genera for species.

<u>**Chapter 3**</u>

1) **Increased environmental self-efficacy is associated with higher self-reported knowledge.** Participants who self-reported higher amounts of invasive species knowledge reported higher confidence (self-efficacy) when it came to managing invasive species. Change in invasive species knowledge due to program participation was not measured directly but participants commented they learned about emerald ash borer and native wasps through Wasp Watchers.
2) **Volunteers who spend more hours participating in the Wasp Watchers citizen science program do not report increased interest in learning, likelihood of advocacy, or environmental self-efficacy.** Separating volunteers into “high” and “low” hours of volunteering and looking for a relationship between volunteering experience and the above constructs revealed no significant self-reported change based on experience. It is possible that the “low” experience group still represented a relatively high experience level, as it included all volunteers who participated for under 10 hours.

3) **Wasp Watchers program participation has additional positive outcomes beyond project outcomes.** Volunteers reported outcomes such as increased community connection, opportunities to reach out to family and friends, and enjoyment of time outdoors. In addition, data collected by volunteers was used to facilitate the creation of both a buprestid beetle checklist for the state and a study on factors influencing buprestid diversity and distribution.

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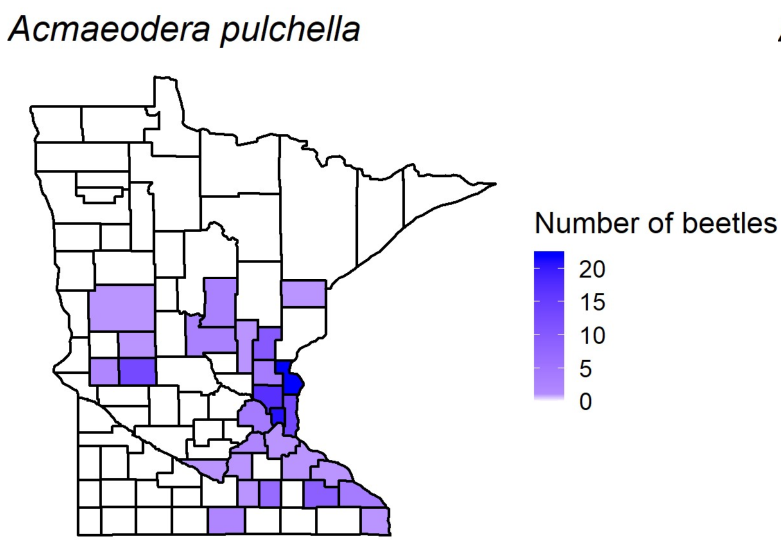
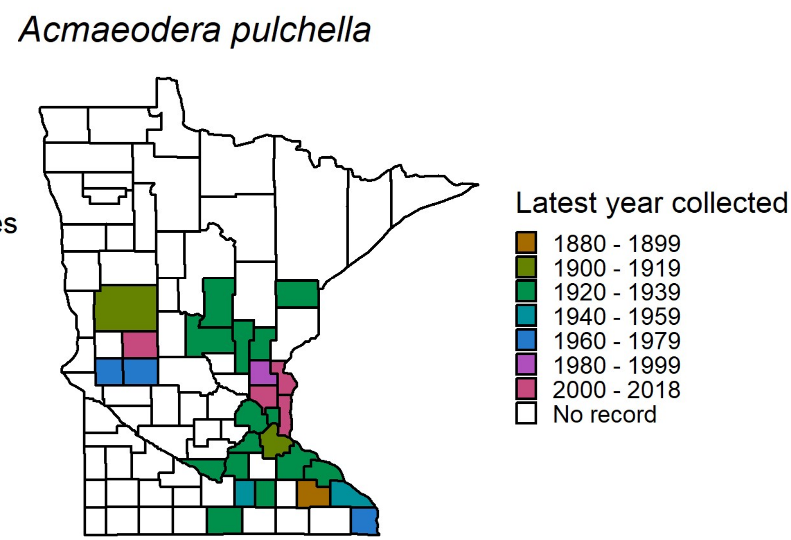
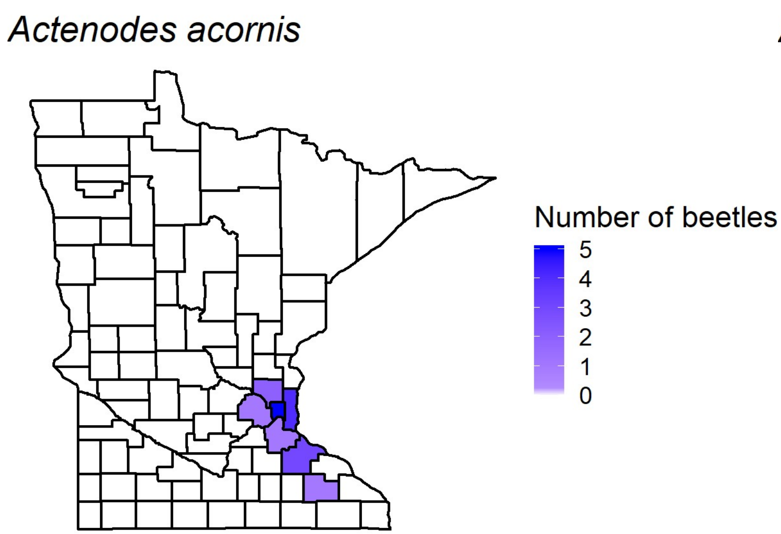
Appendix

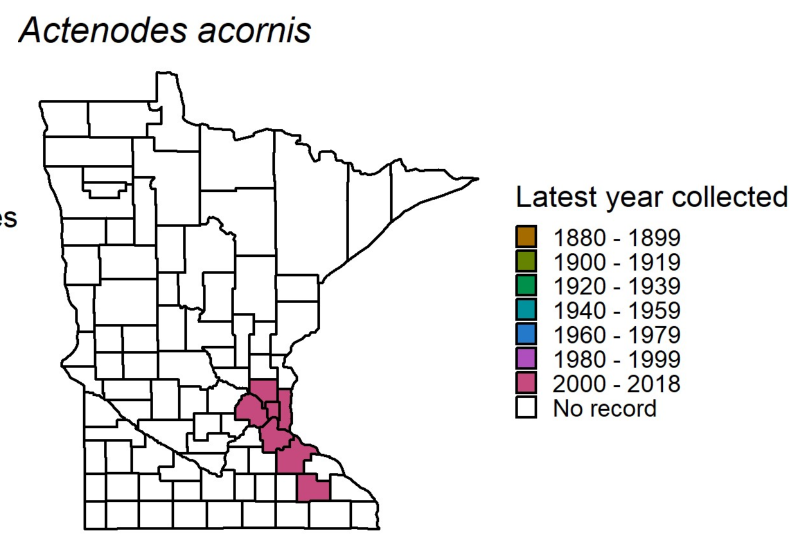
1.1 *Species distribution maps*

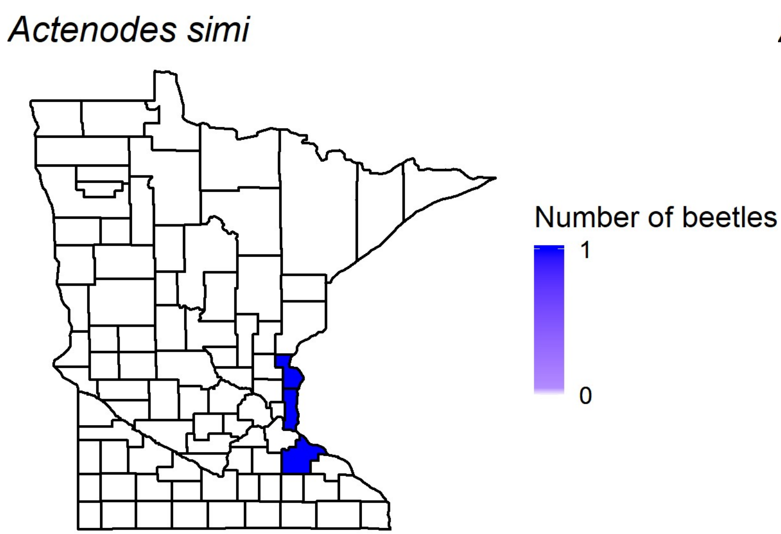
Maps on the left display the number of individuals collected by county as described in the University of Minnesota Insect Collection, with darker colors indicating a greater number of beetles. Maps on the right display most recent collection date in 20 year intervals. Some museum labels had locality information but no date information, and these are included in the count maps only. Species are listed alphabetically.

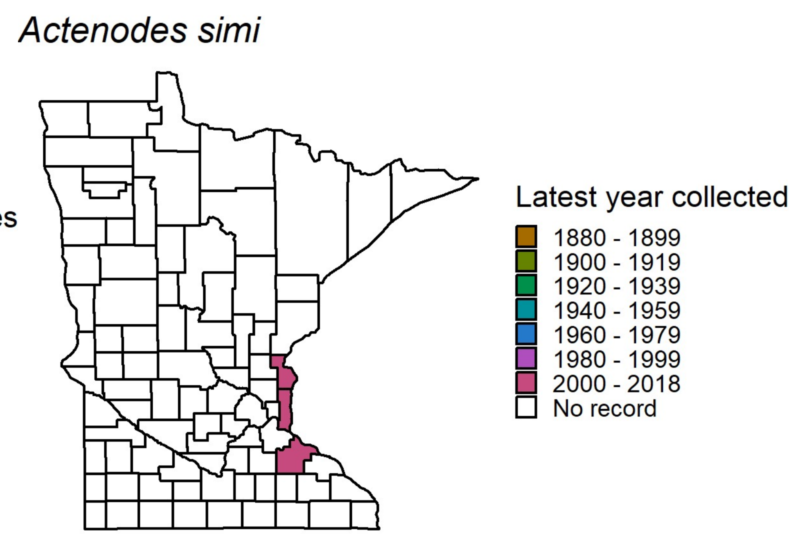

Acmaeodera pulchella
Number of beetles
20
15
10
5
0


Acmaeodera pulchella
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Actenodes acornis
Number of beetles
5
4
3
2
1
0


Actenodes acornis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Actenodes simi
Number of beetles
1
0


Actenodes simi
Latest year collected
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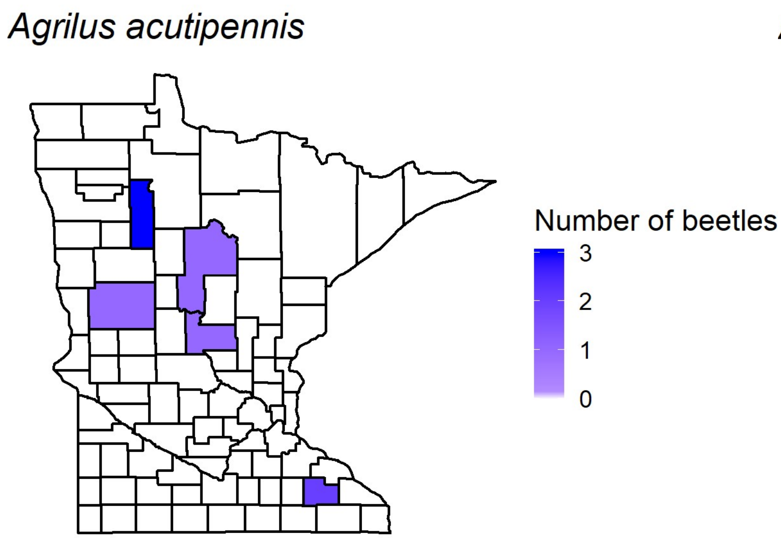
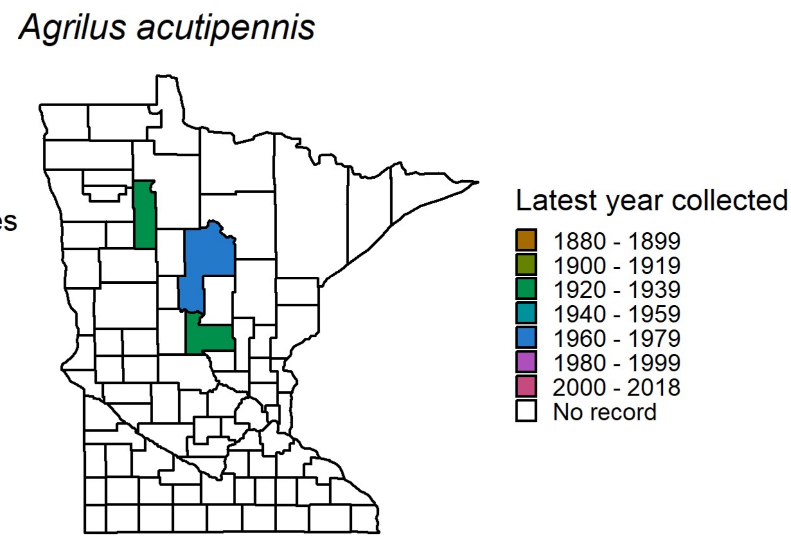
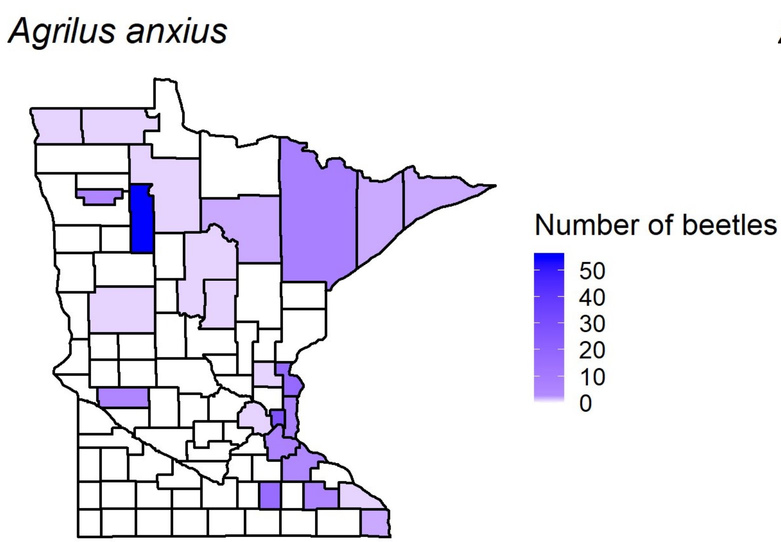
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus acutipennis
Number of beetles
3
2
1
0


Agrilus acutipennis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus anxius
Number of beetles
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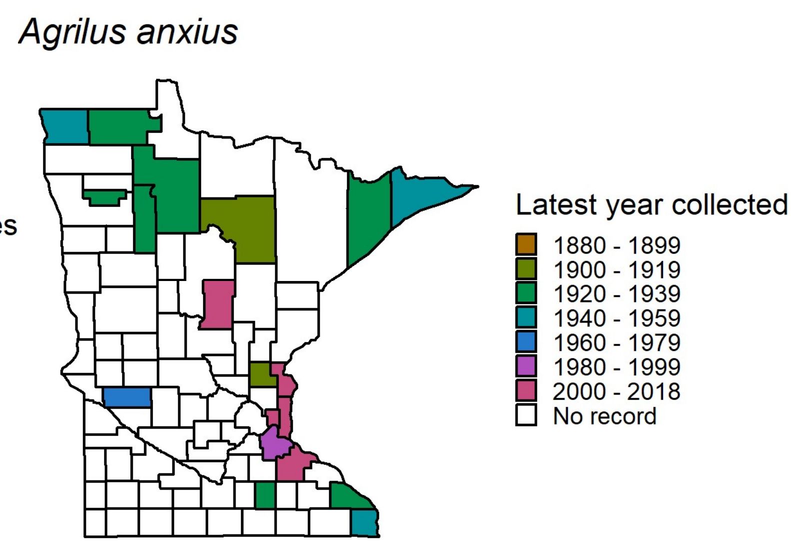
40
30
20
10
0


Agrilus anxius
Latest year collected
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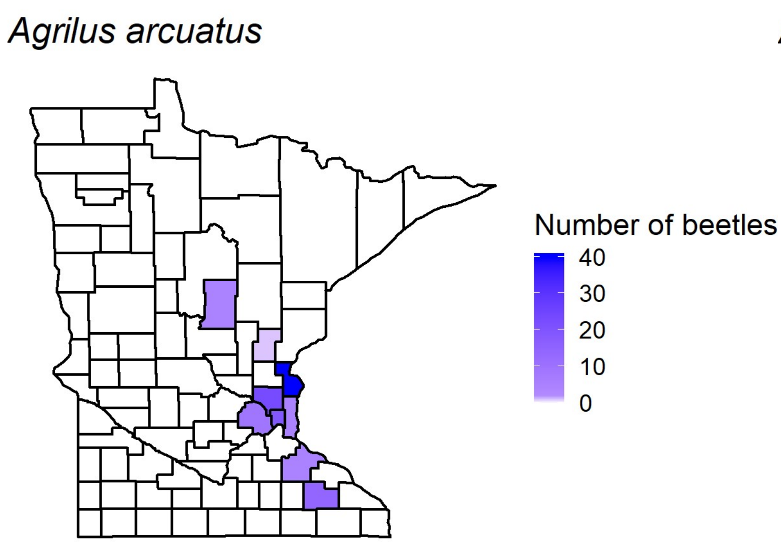
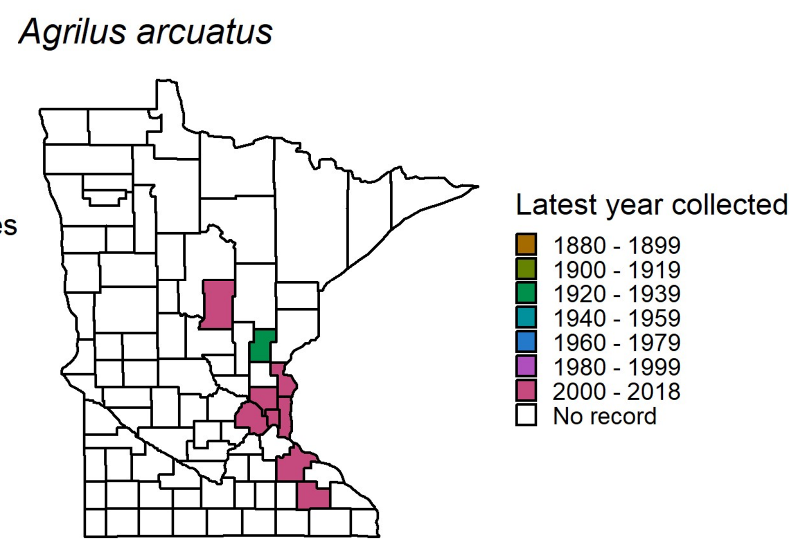
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus arcuatus
Number of beetles
40
30
20
10
0


Agrilus arcuatus
Latest year collected
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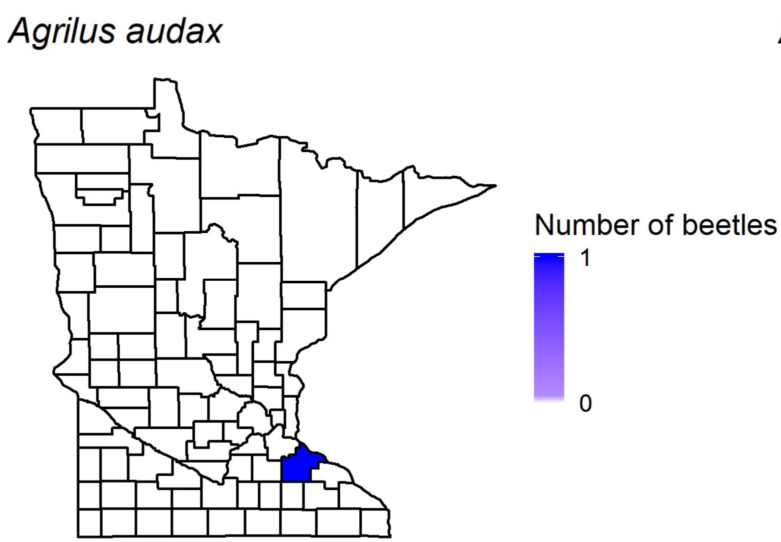
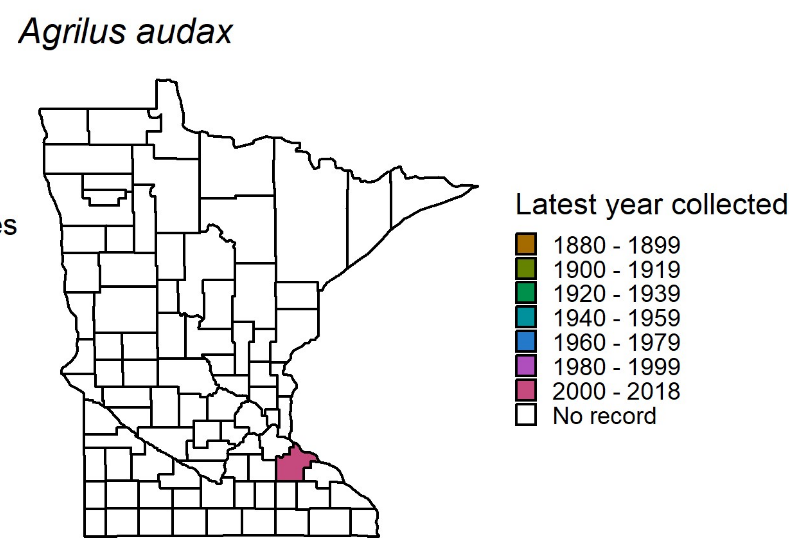
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus audax
Number of beetles
1
0


Agrilus audax
Latest year collected
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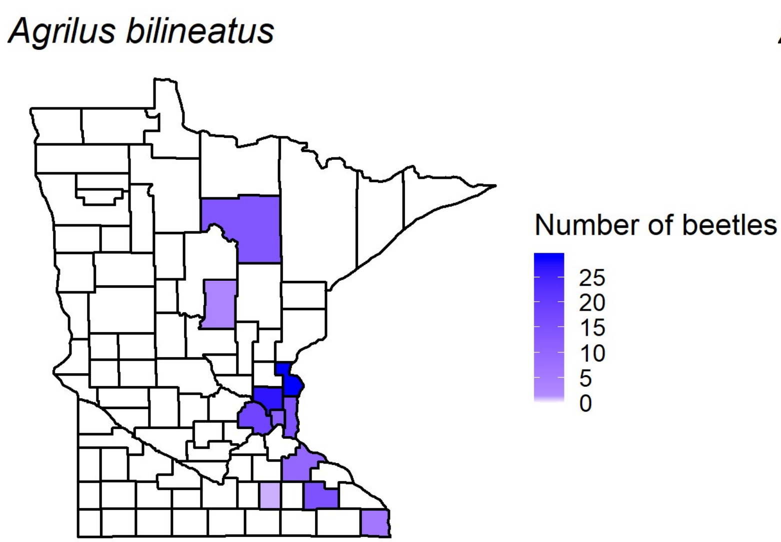
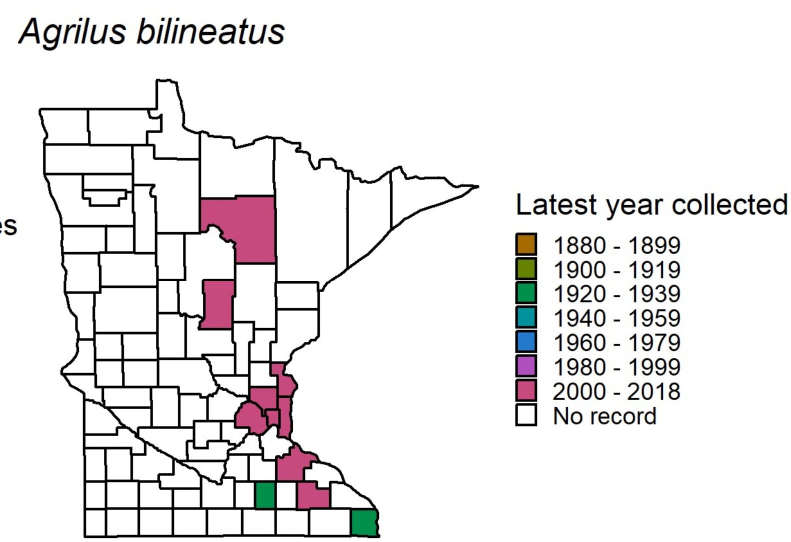
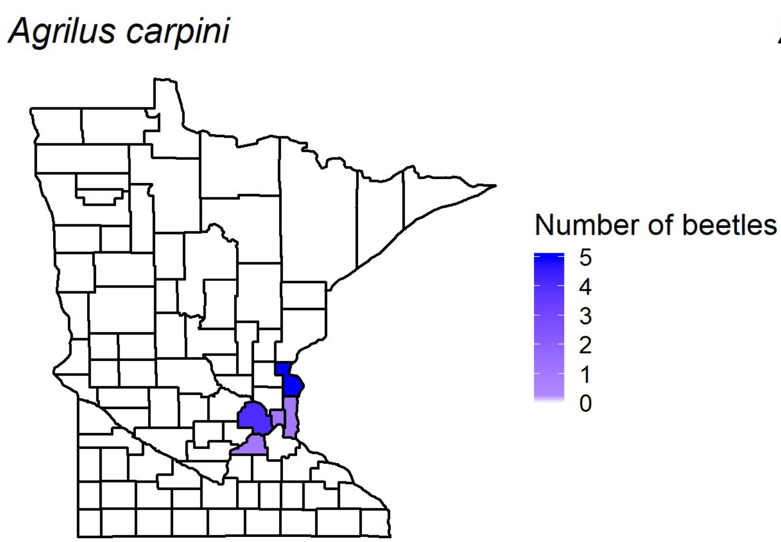
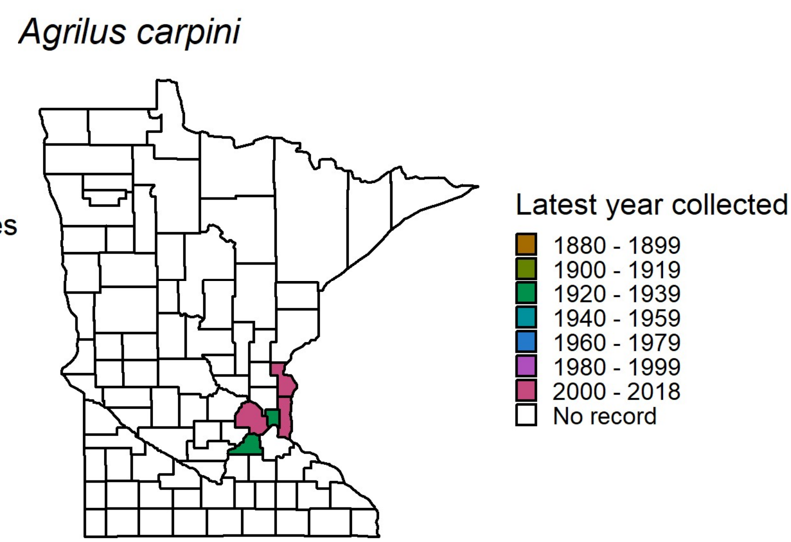
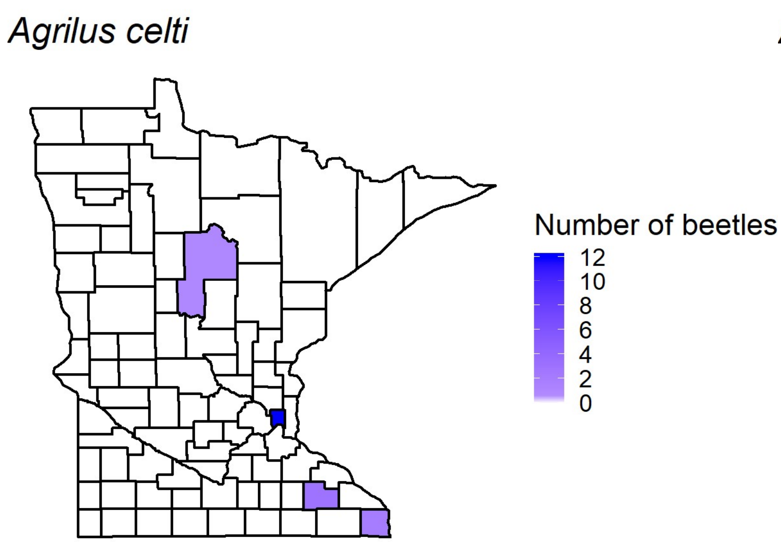
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus bilineatus
Number of beetles
25
20
15
10
5
0

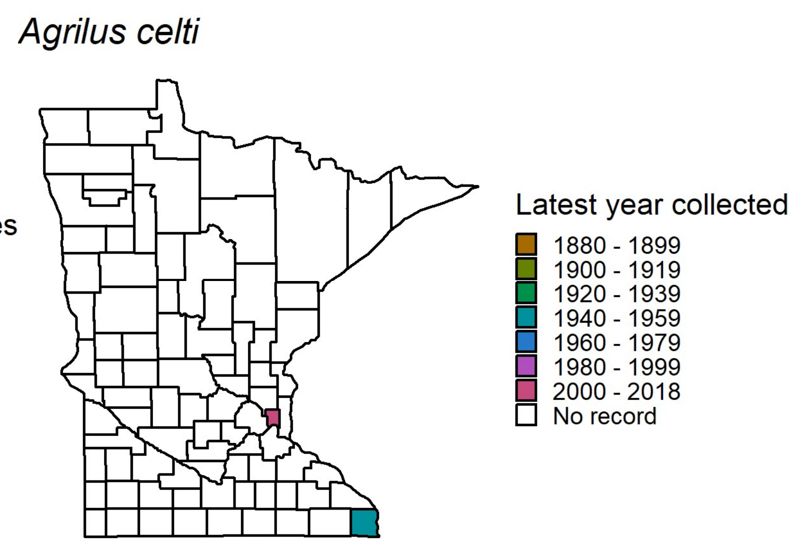

Agrilus bilineatus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus carpini
Number of beetles
5
4
3
2
1
0

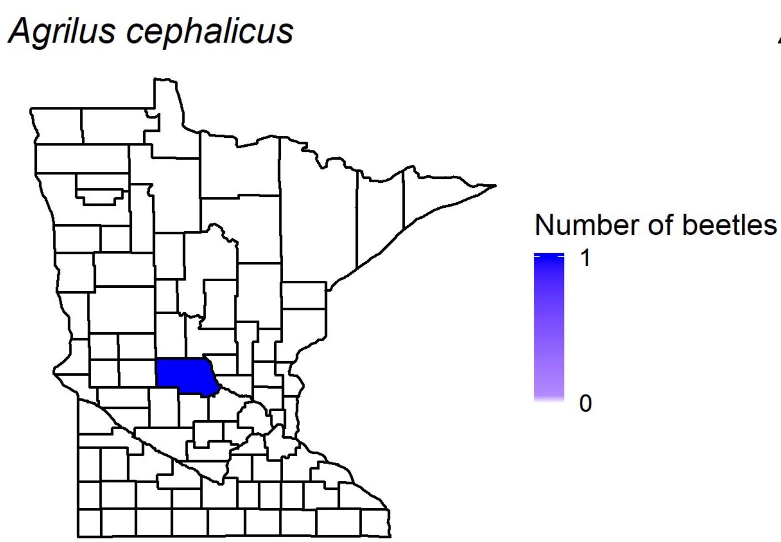

Agrilus carpini
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

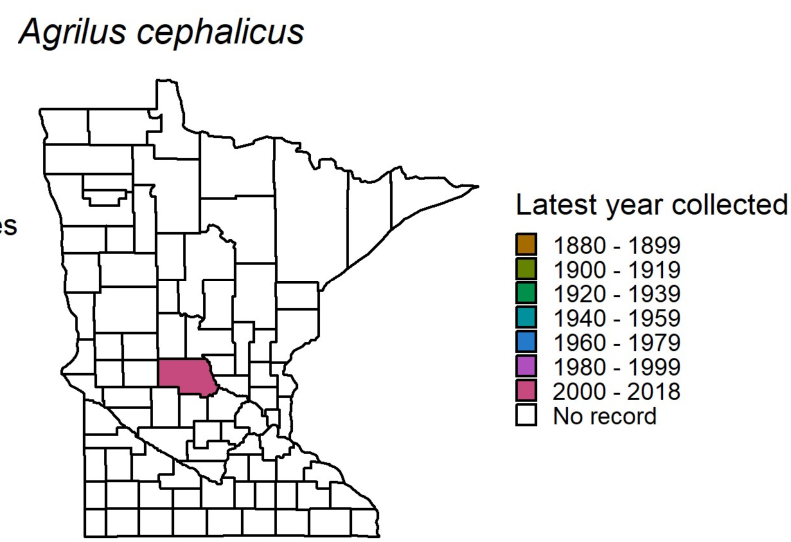


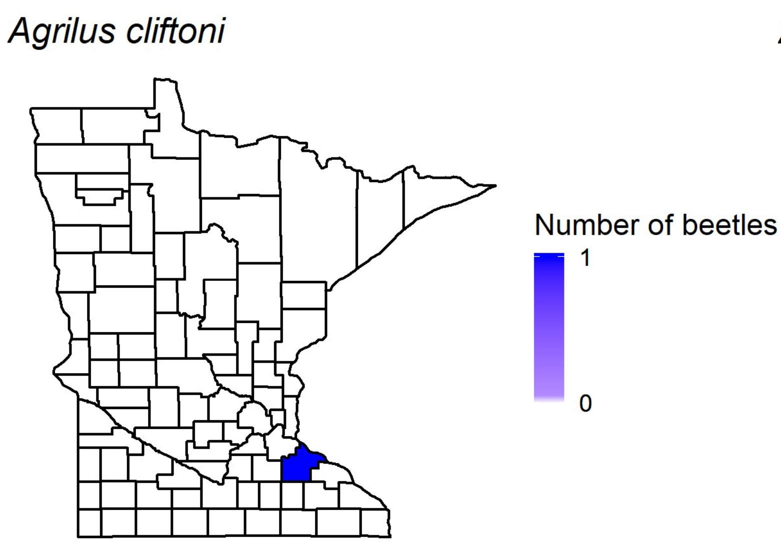
Agrilus celti
Number of beetles
12
10
8
6
4
2
0

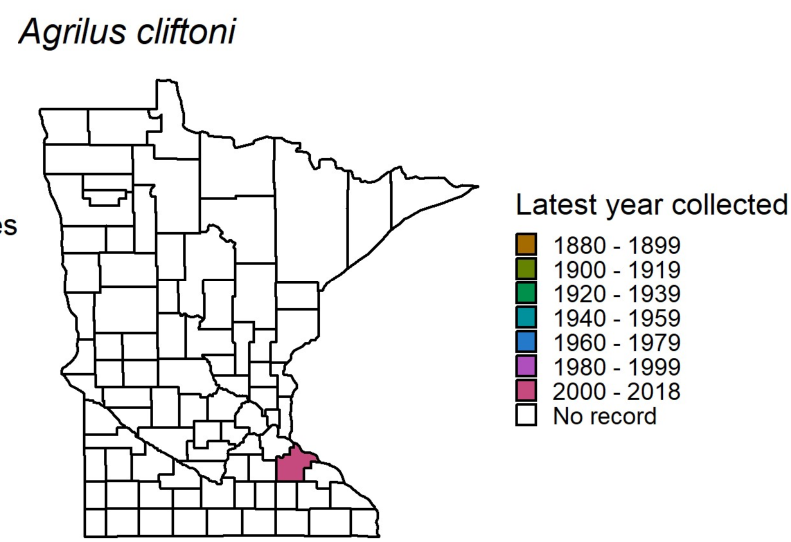


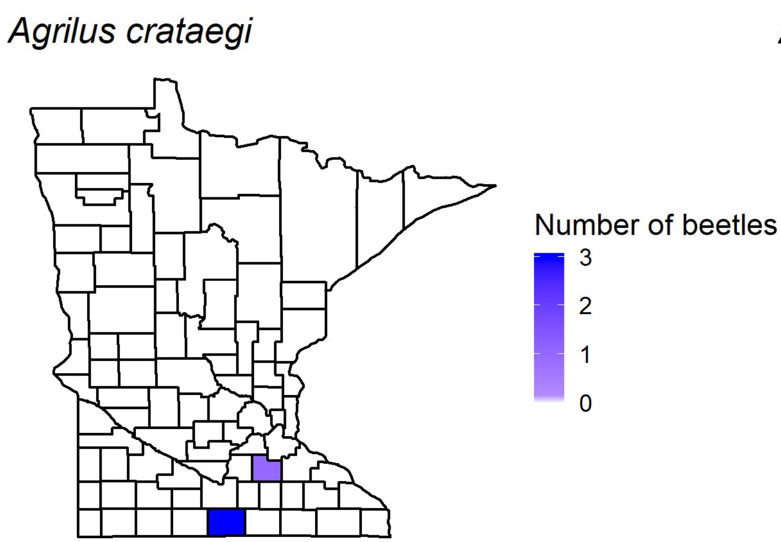
Agrilus celti
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

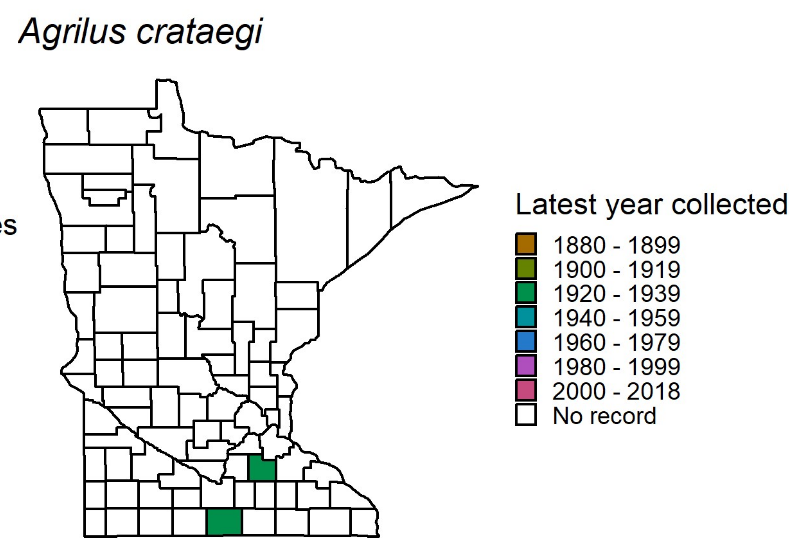

Agrilus cephalicus
Number of beetles
1
0

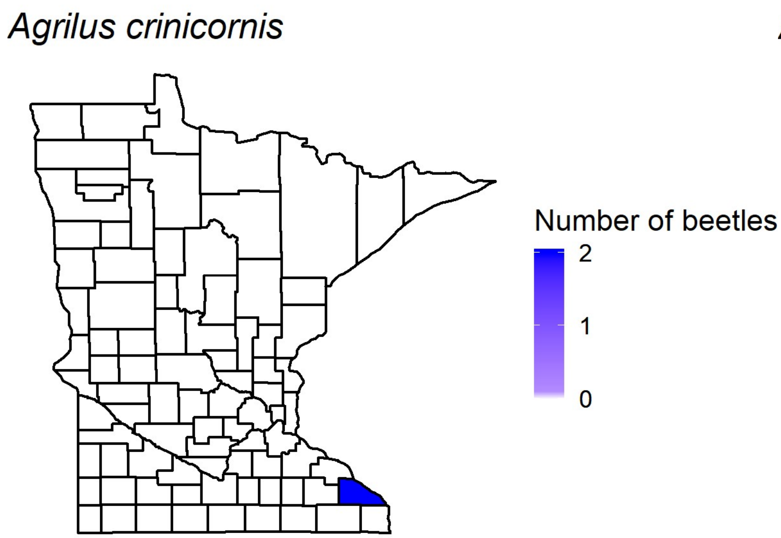

Agrilus cephalicus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

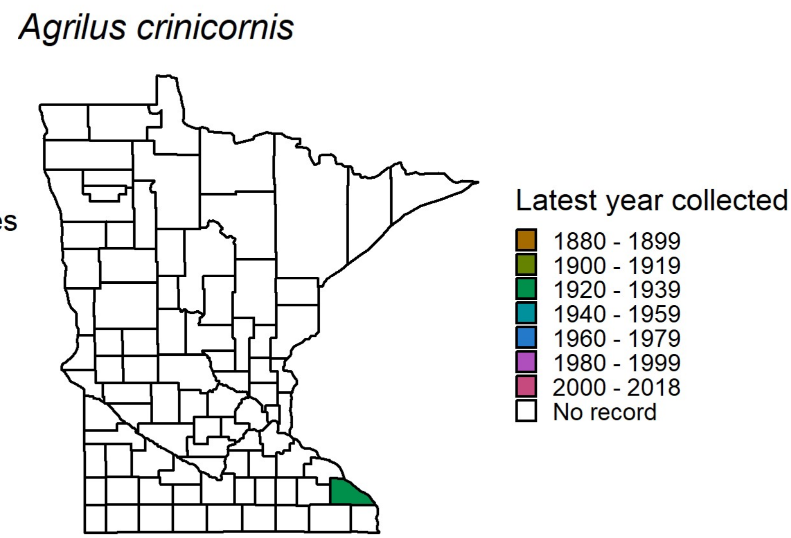

Agrilus cliftoni
Number of beetles
1
0

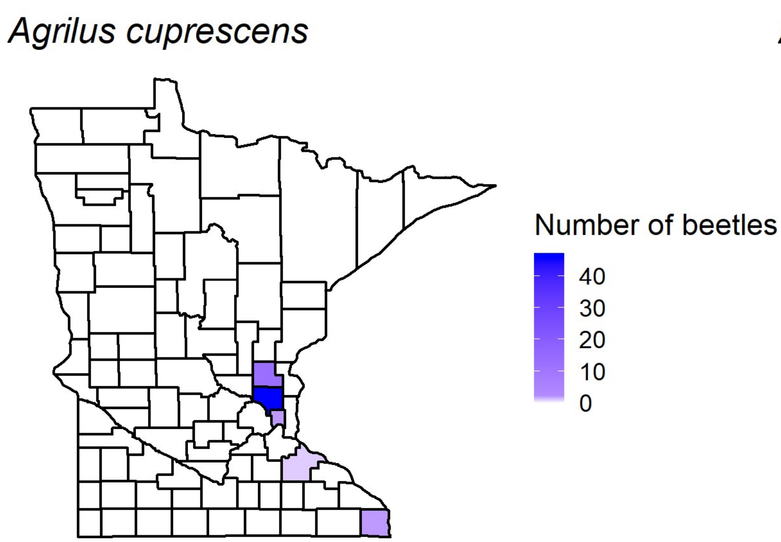

Agrilus cliftoni
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

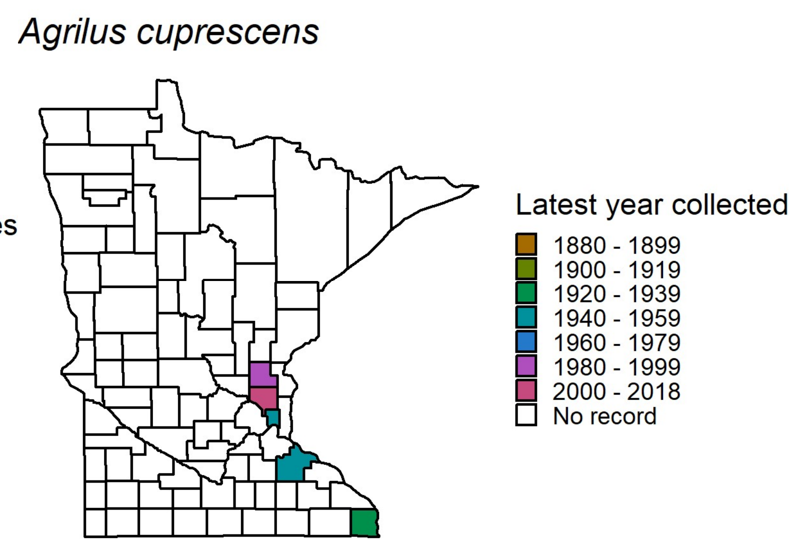

Agrilus crataegi
Number of beetles
3
2
1
0

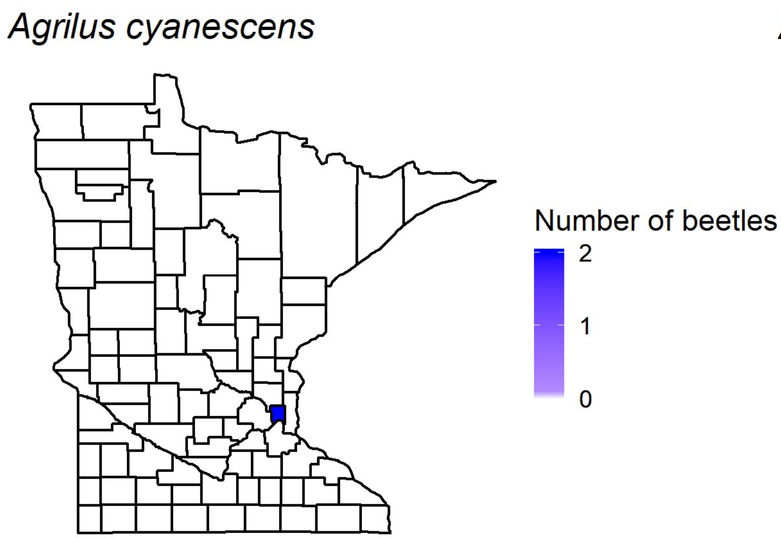

Agrilus crataegi
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

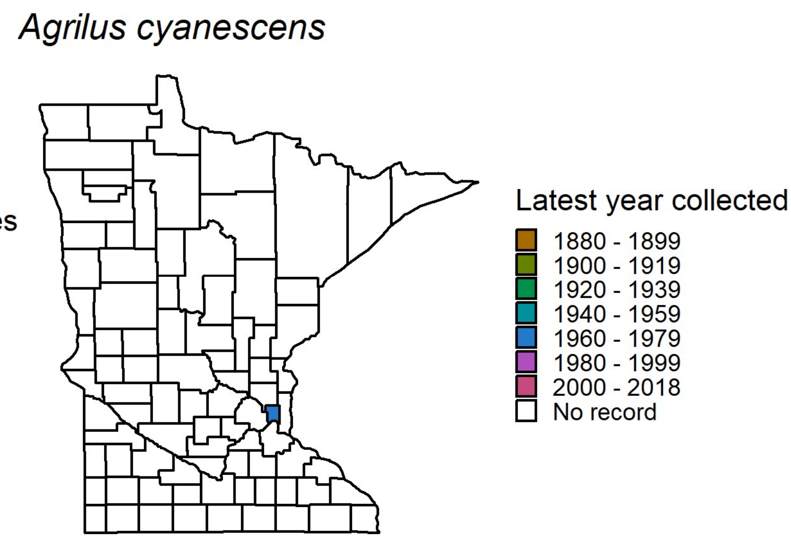

Agrilus crinicornis
Number of beetles
2
1
0

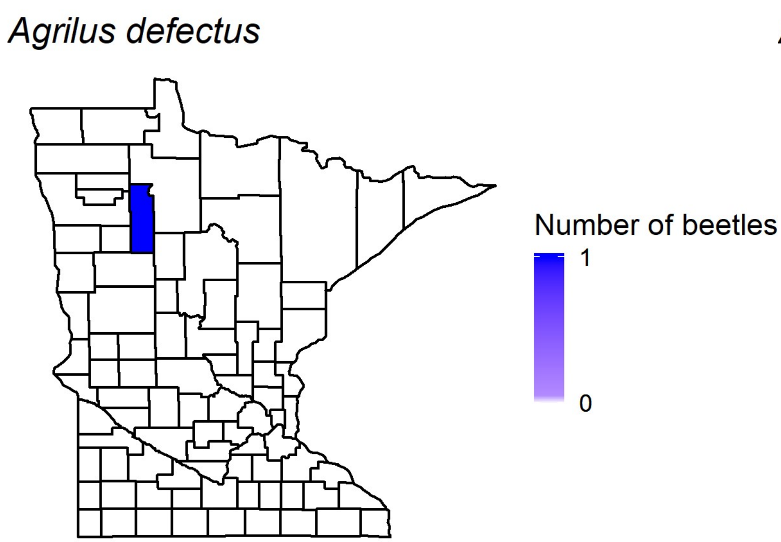

Agrilus crinicornis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

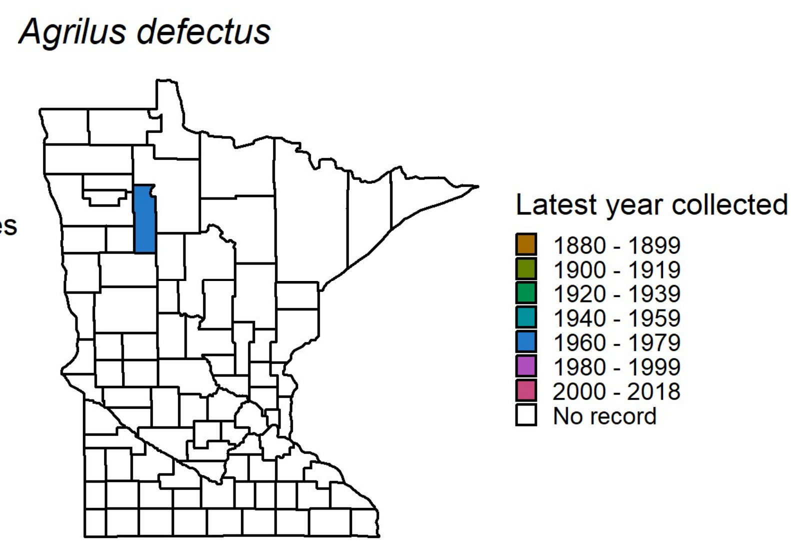

Agrilus cuprescens
Number of beetles
40
30
20
10
0

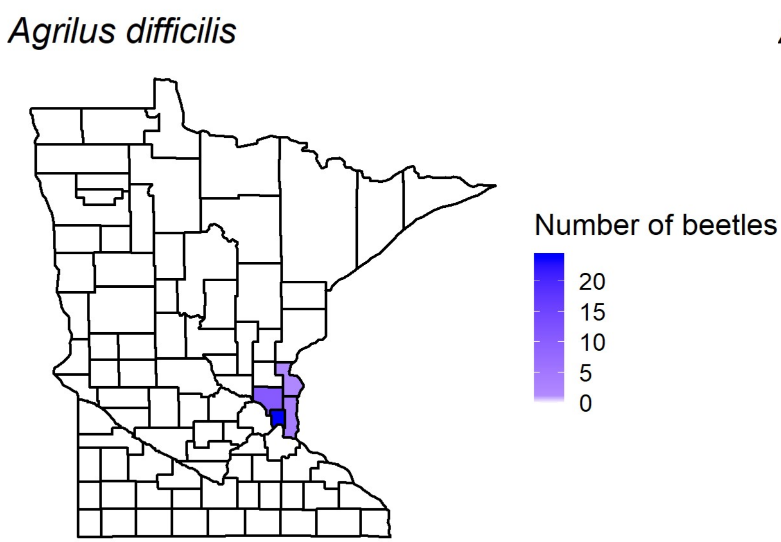

Agrilus cuprescens
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

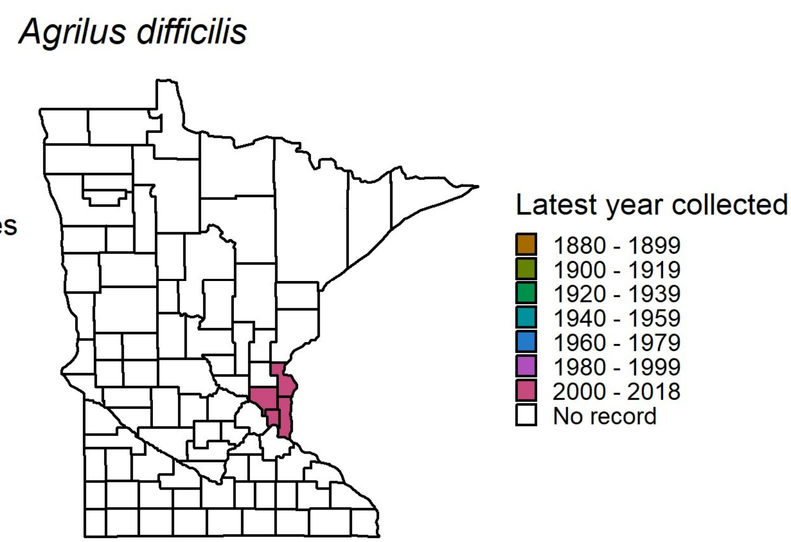

Agrilus cyanescens
Number of beetles
2
1
0


Agrilus cyanescens
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus defectus
Number of beetles
1
0


Agrilus defectus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus difficilis
Number of beetles
20
15
10
5
0


Agrilus difficilis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
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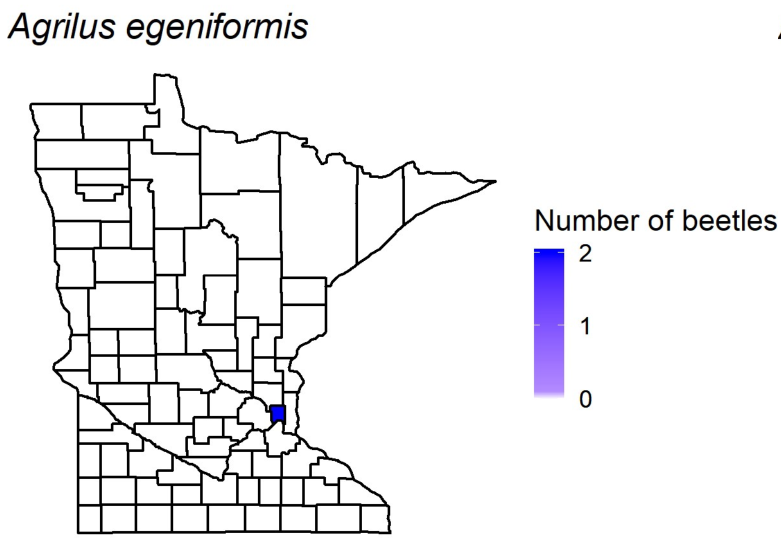
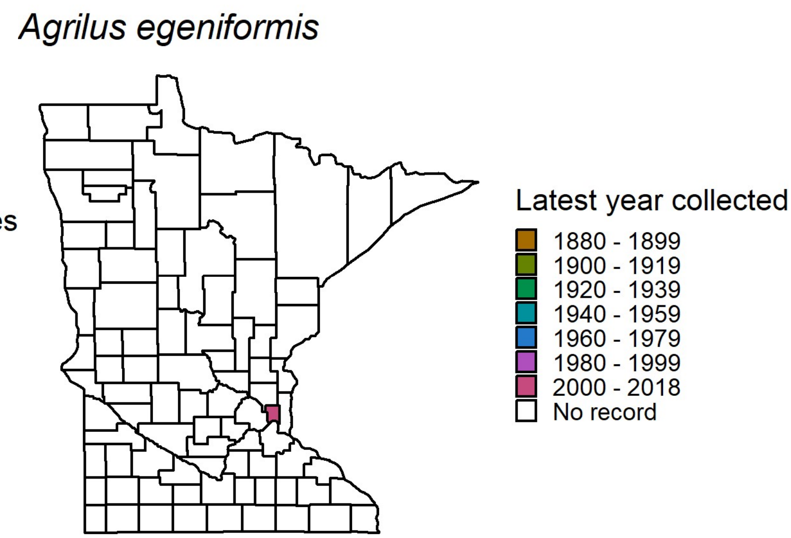


Agrilus egeniformis
Number of beetles
2
1
0



Agrilus egeniformis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
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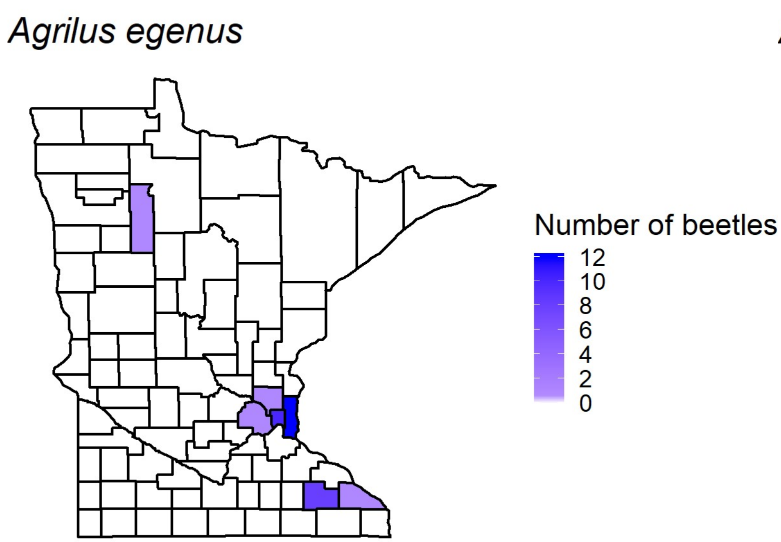
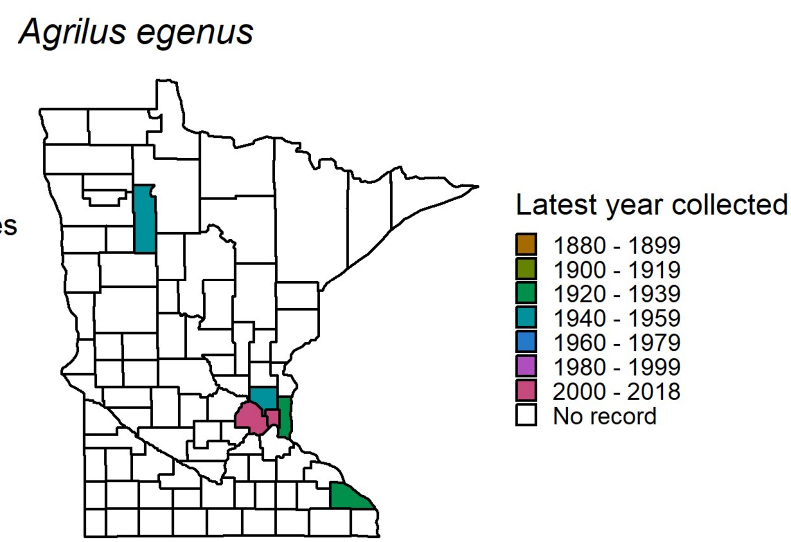
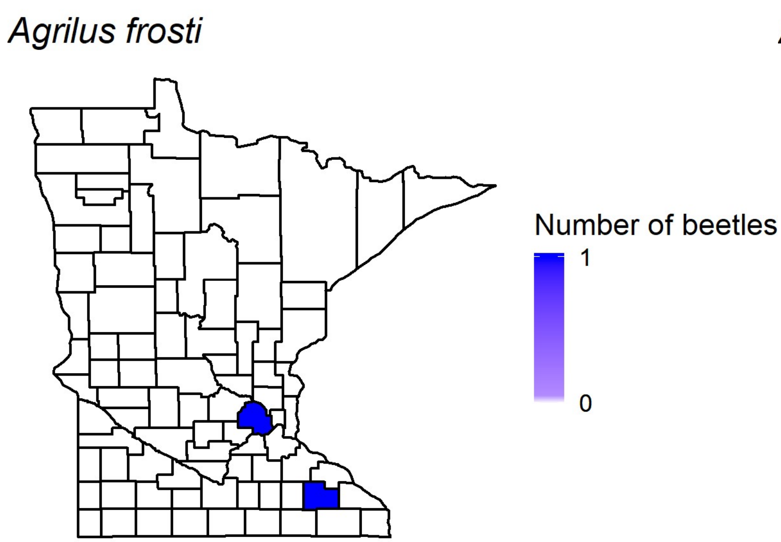
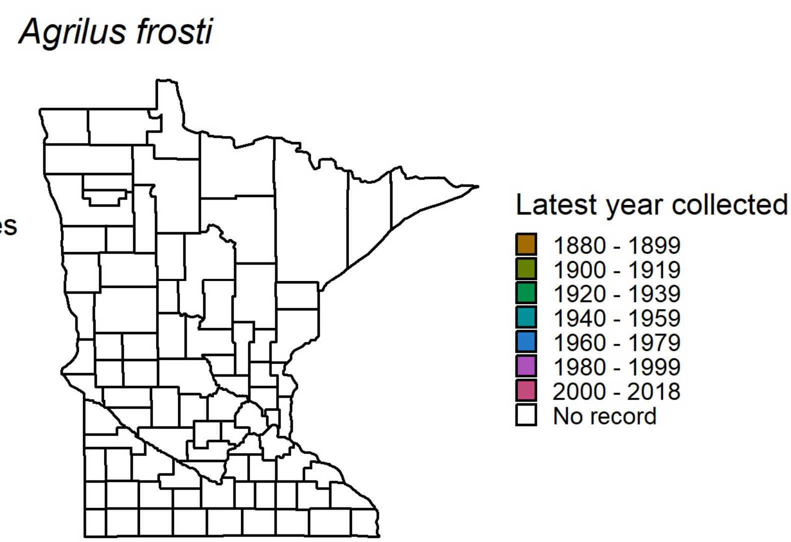
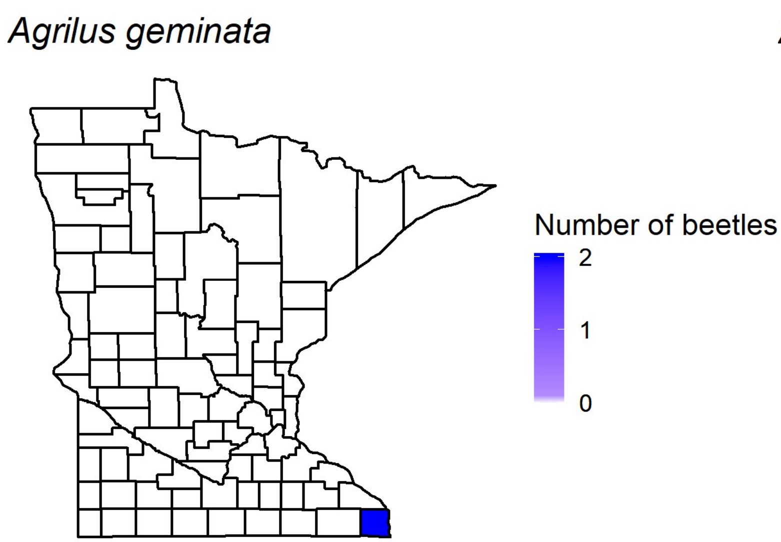
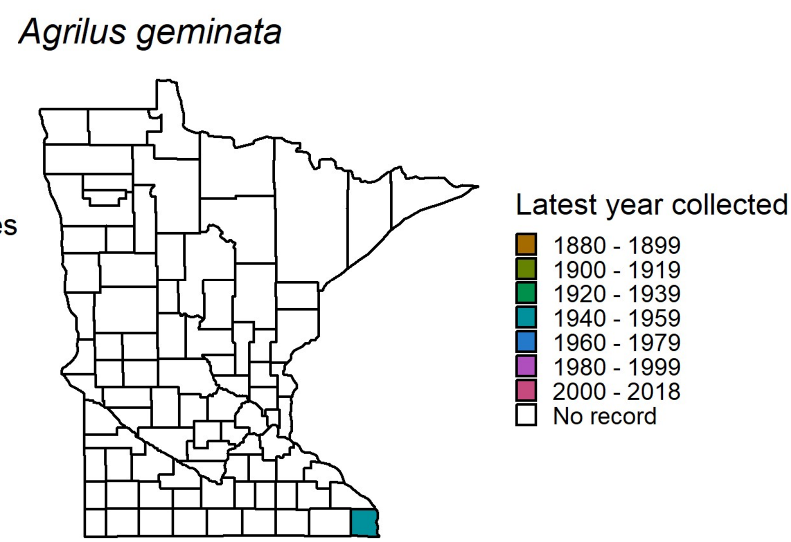

Agrilus egenus
Number of beetles
12
10
8
6
4
2
0


Agrilus egenus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus frosti
Number of beetles
1
0


Agrilus frosti
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus geminata
Number of beetles
2
1
0


Agrilus geminata
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
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2000 - 2018
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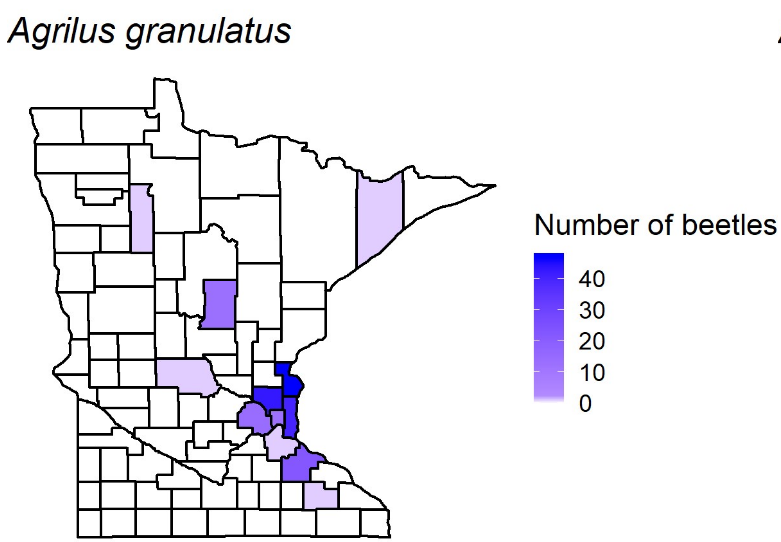
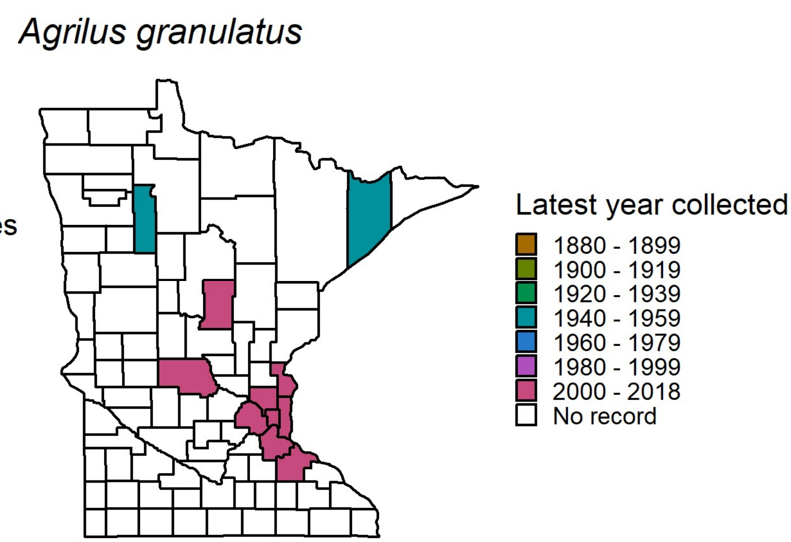
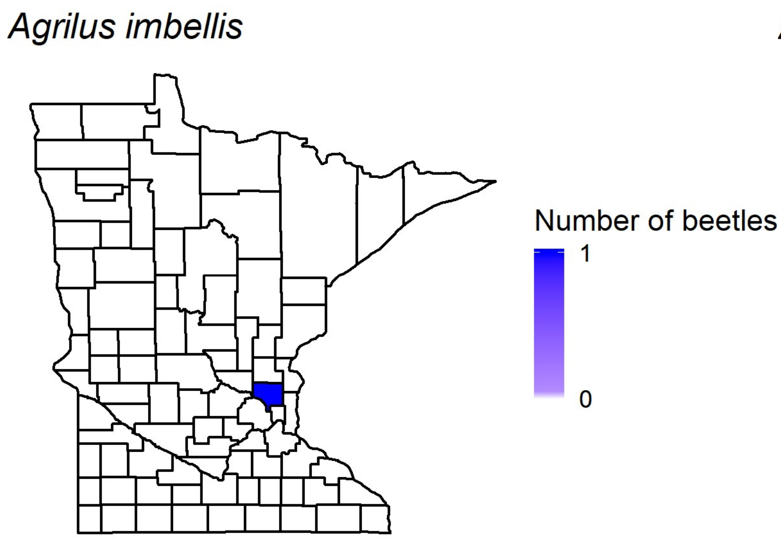
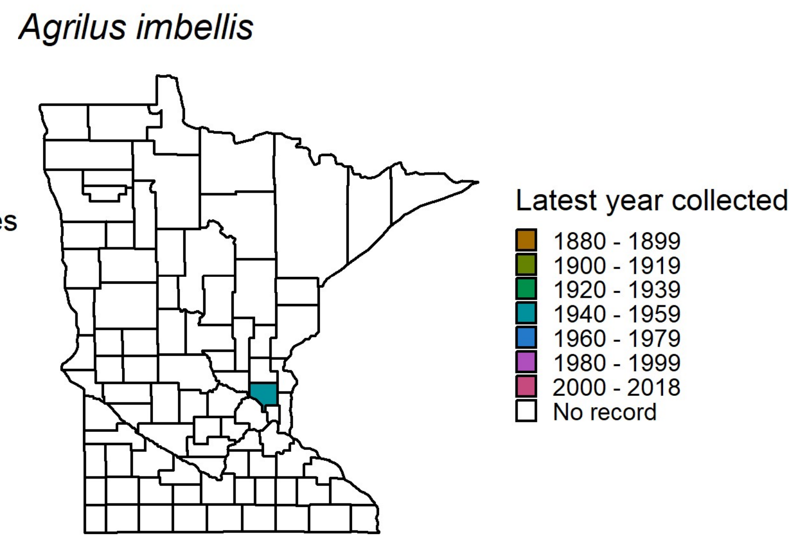
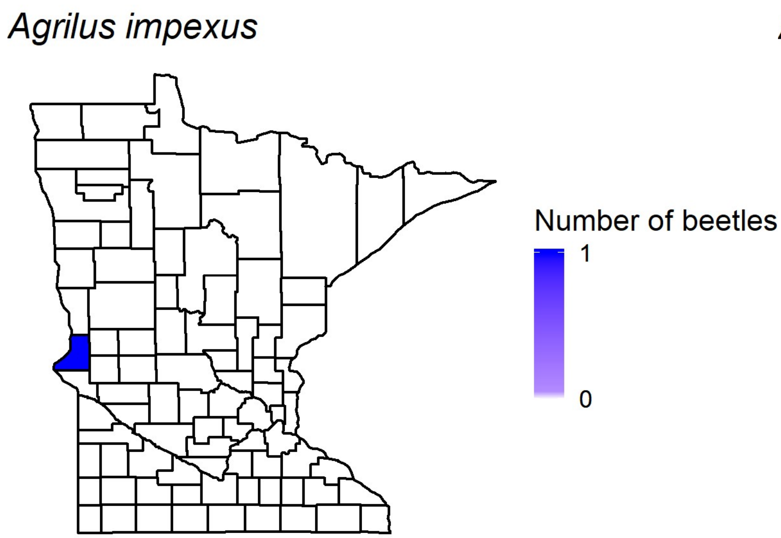
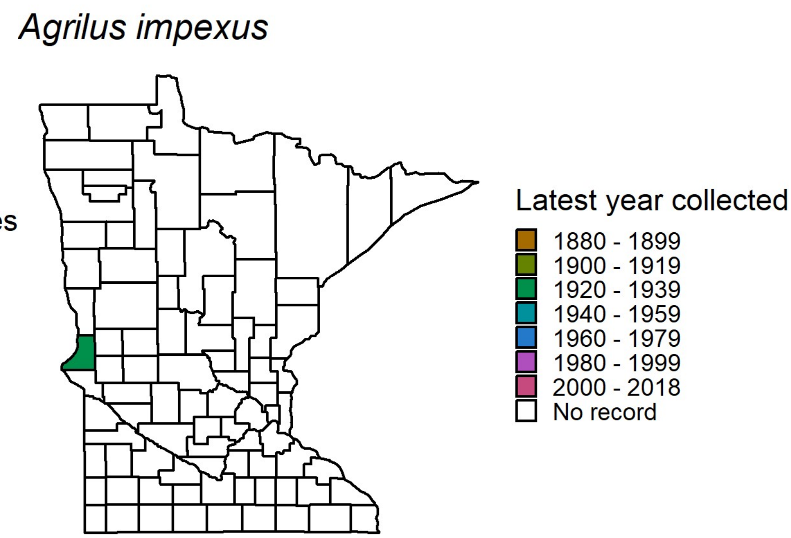

Agrilus granulatus
Number of beetles
40
30
20
10
0

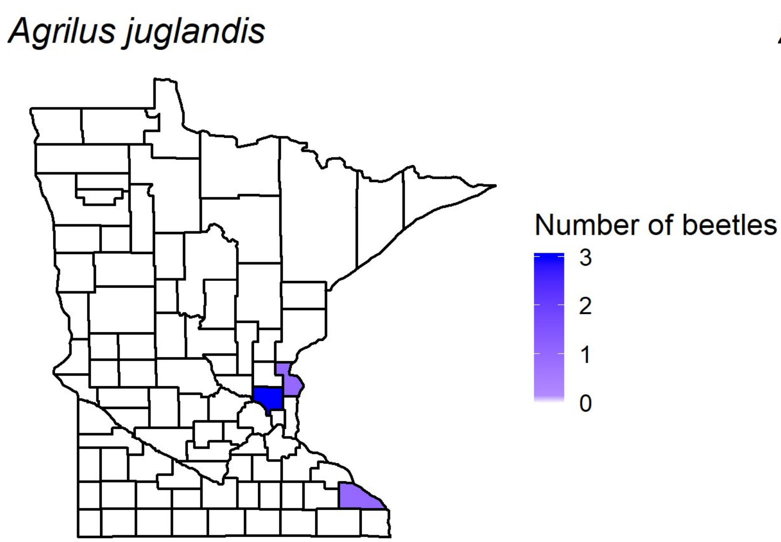

Agrilus granulatus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus imbellis
Number of beetles
1
0

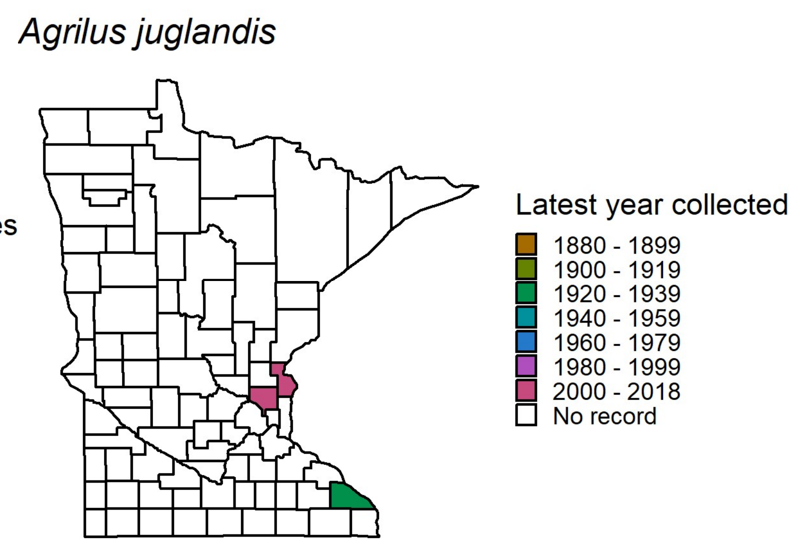

Agrilus imbellis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus impexus
Number of beetles
1
0

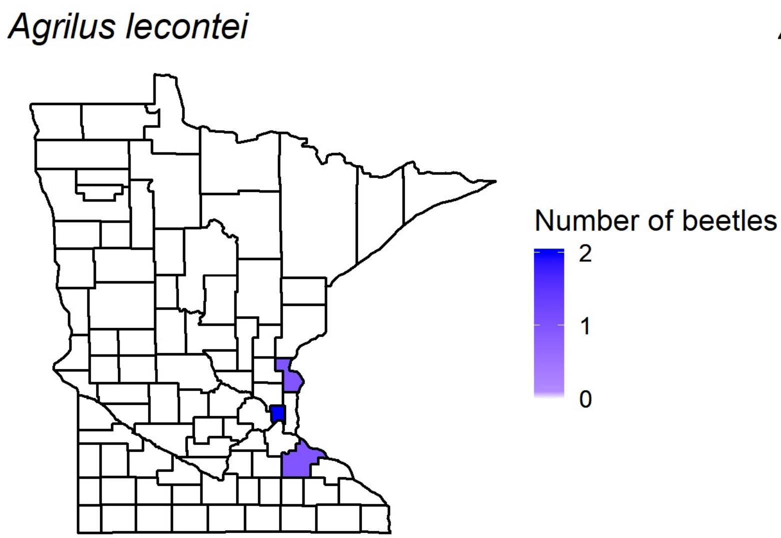

Agrilus impexus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

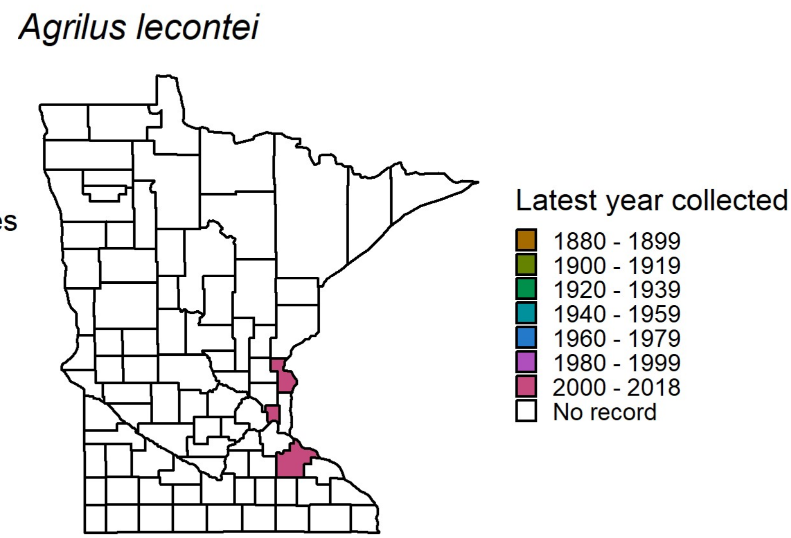


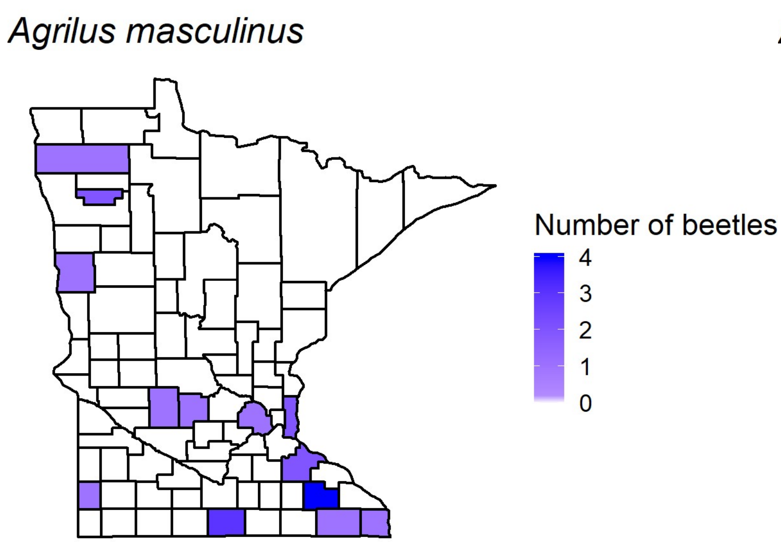
Agrilus juglandis
Number of beetles
3
2
1
0

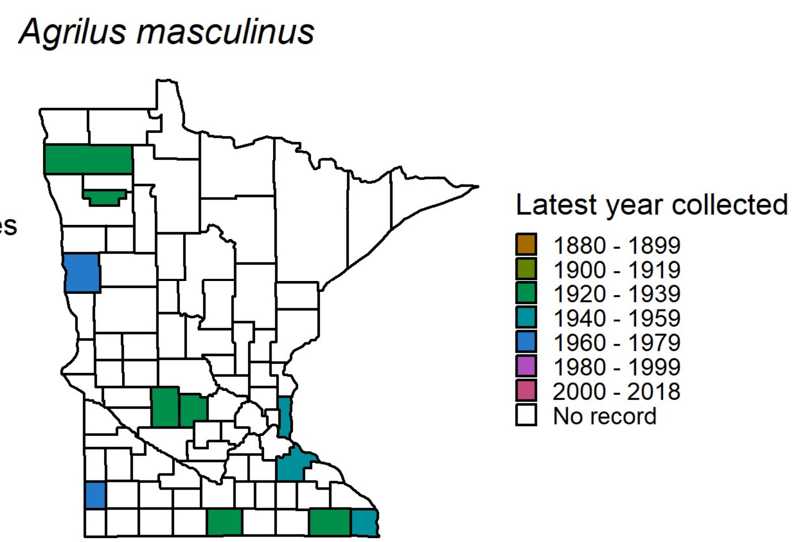


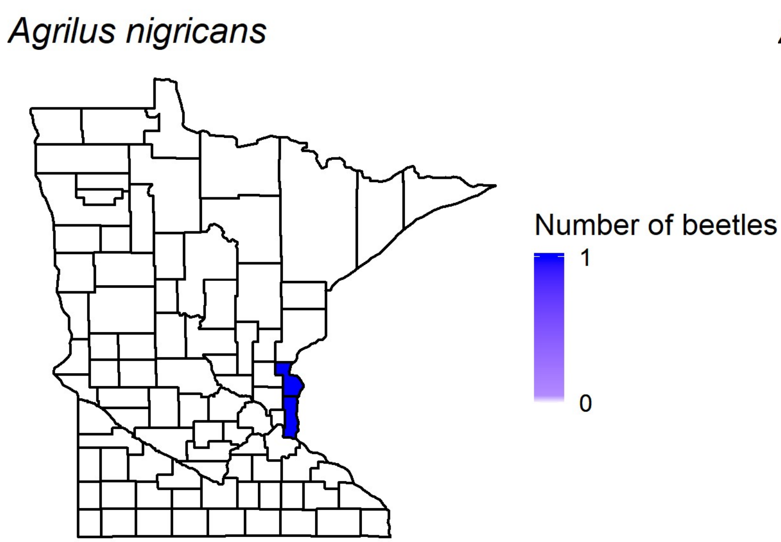
Agrilus juglandis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus lecontei
Number of beetles
2
1
0

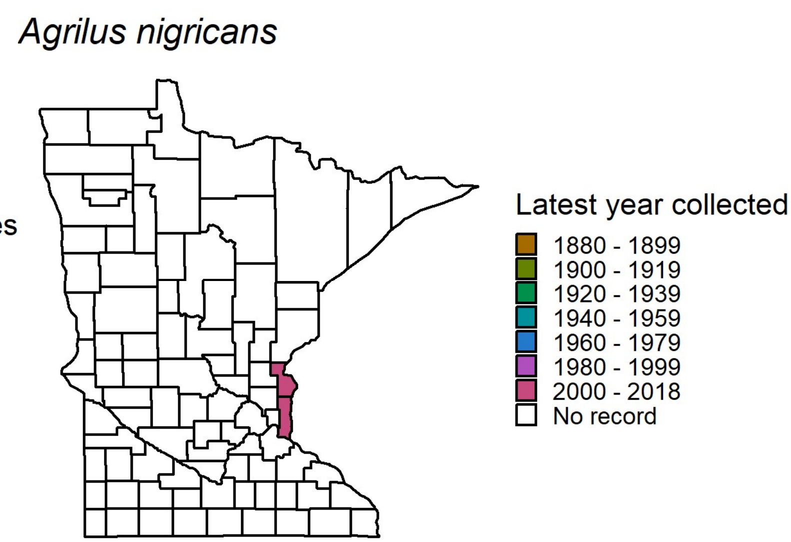

Agrilus lecontei
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus masculinus
Number of beetles
4
3
2
1
0

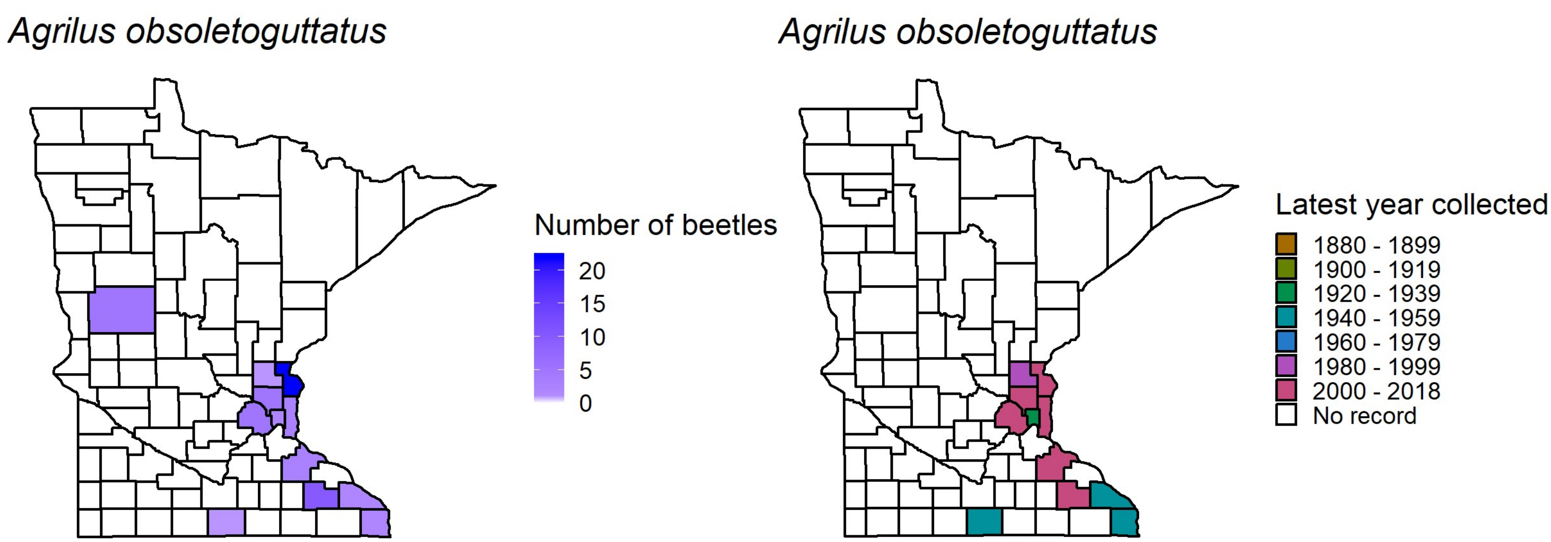

Agrilus masculinus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

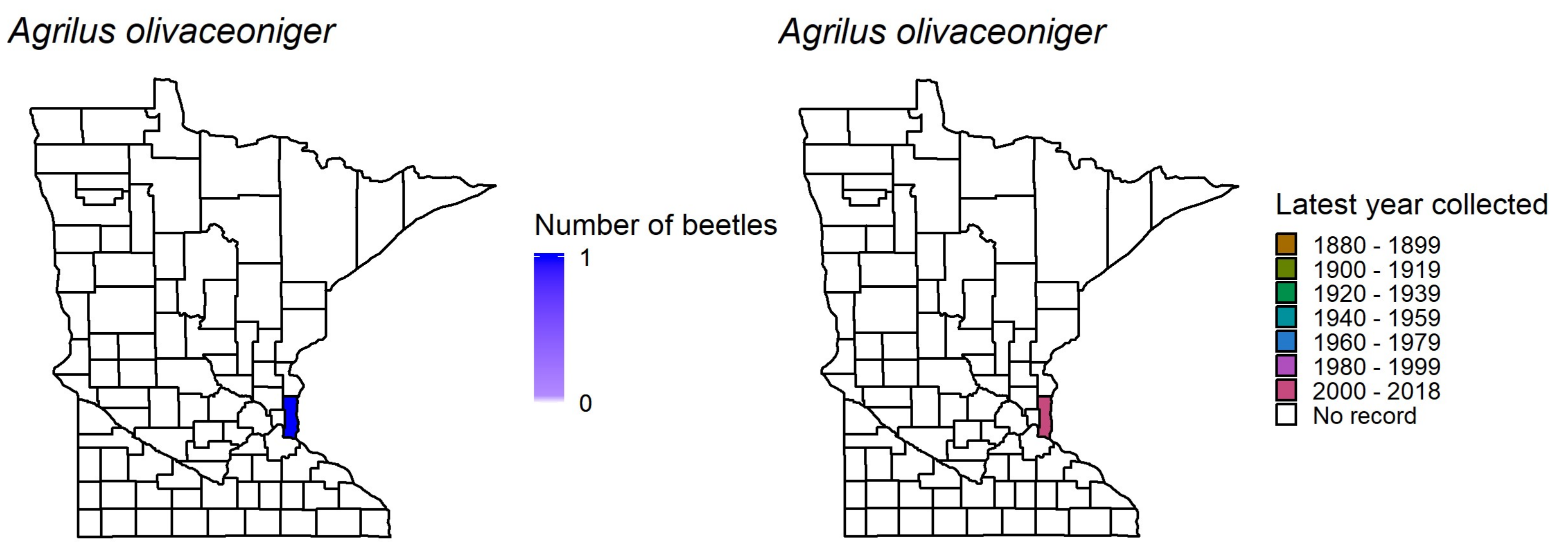


Agrilus nigricans
Number of beetles
1
0

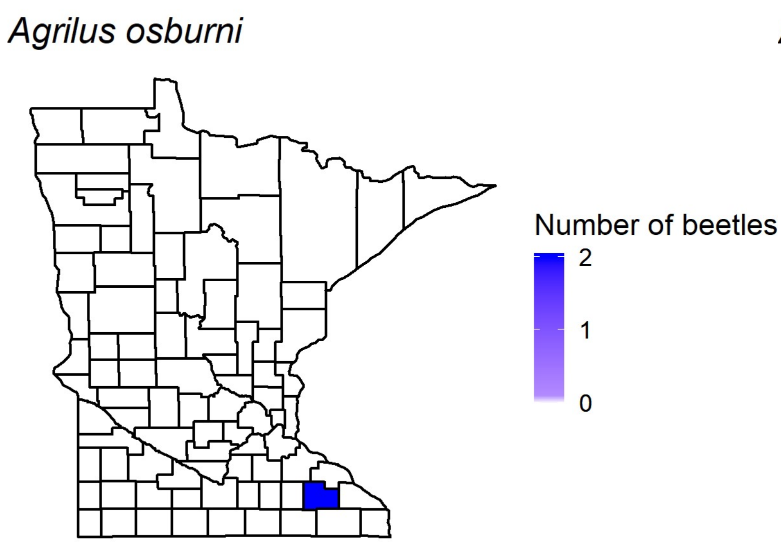


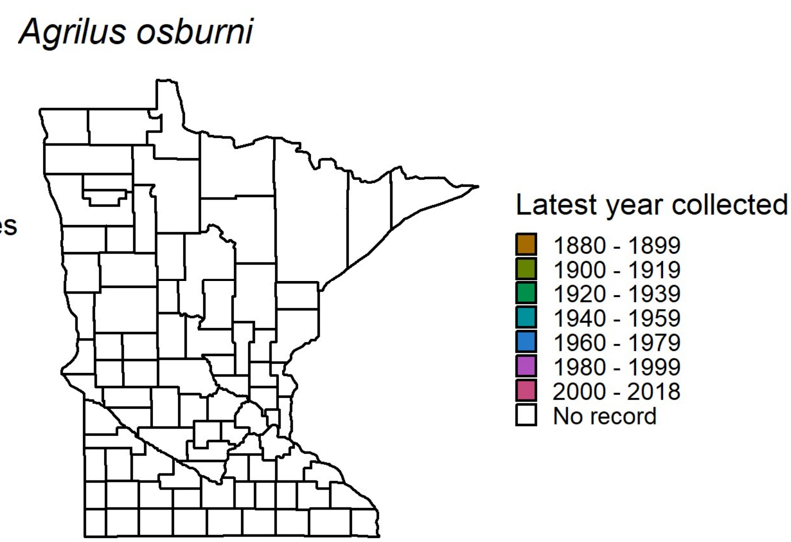
Agrilus nigricans
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

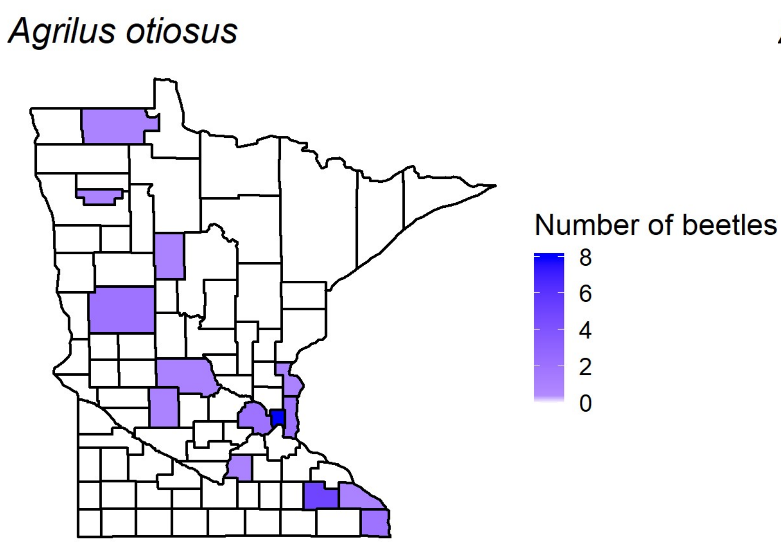

Agrilus obsoletoguttatus
Number of beetles
20
15
10
5
0
Agrilus obsoletoguttatus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

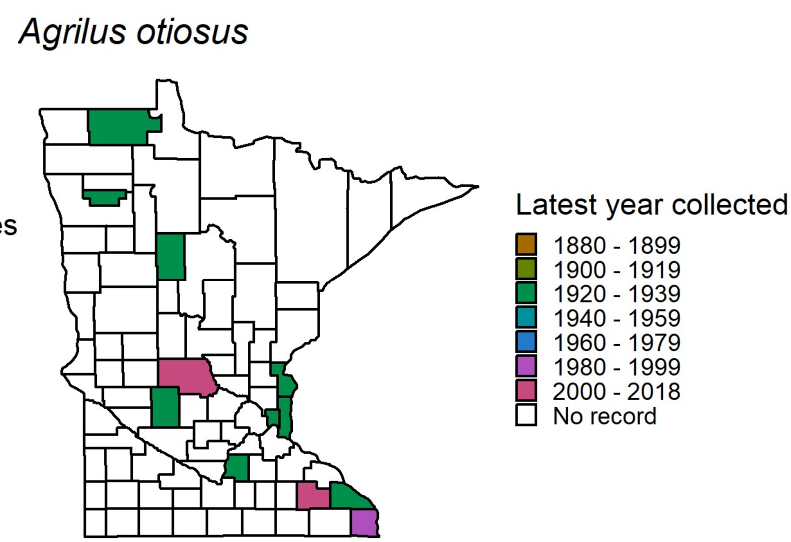


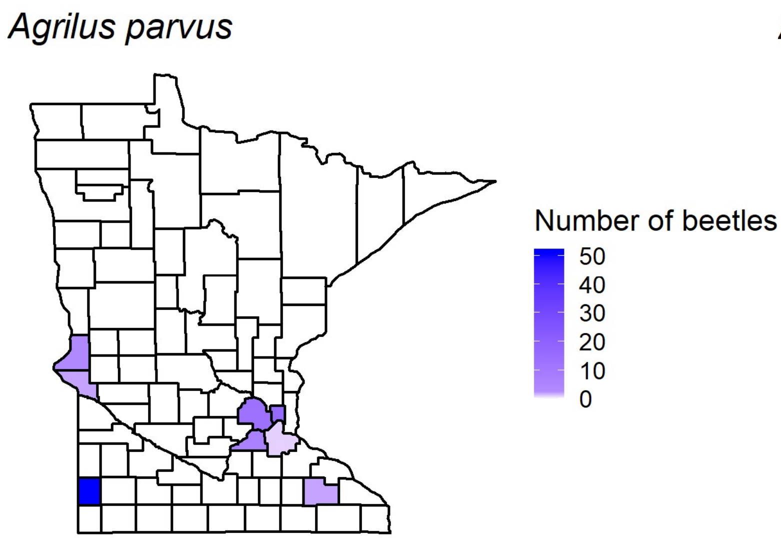
Agrilus olivaceoniger
Number of beetles
1
0
Agrilus olivaceoniger
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

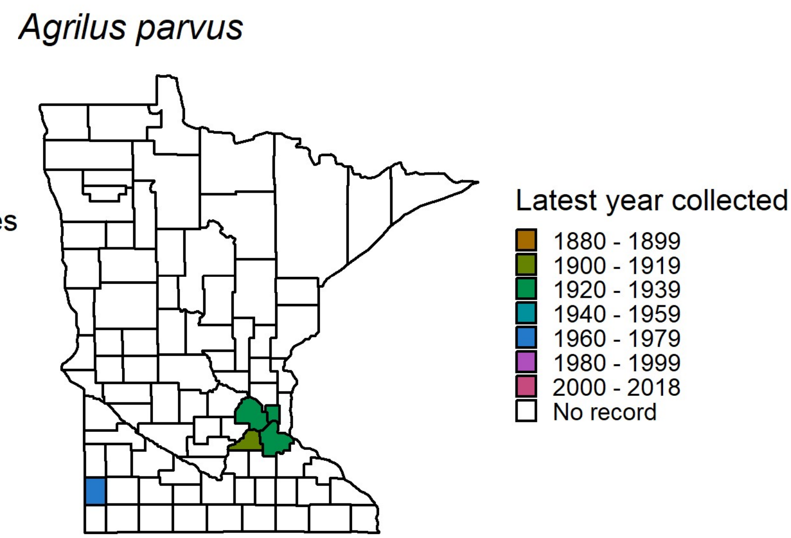

Agrilus osburni
Number of beetles
2
1
0

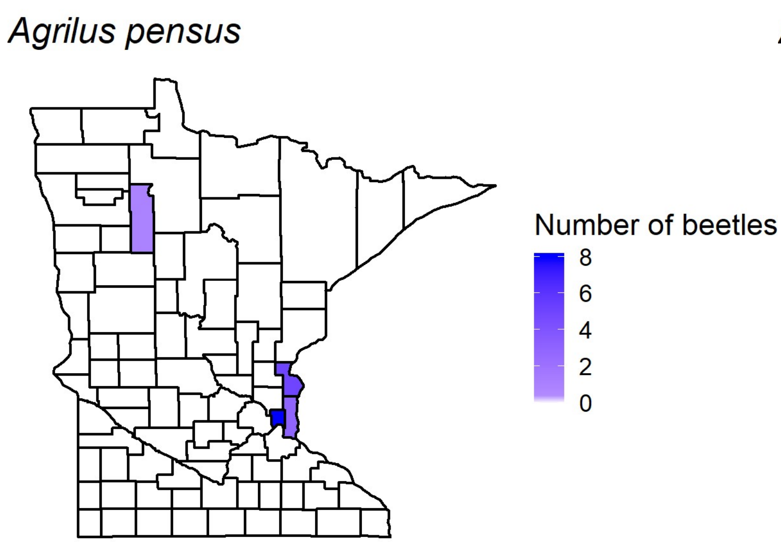

Agrilus osburni
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

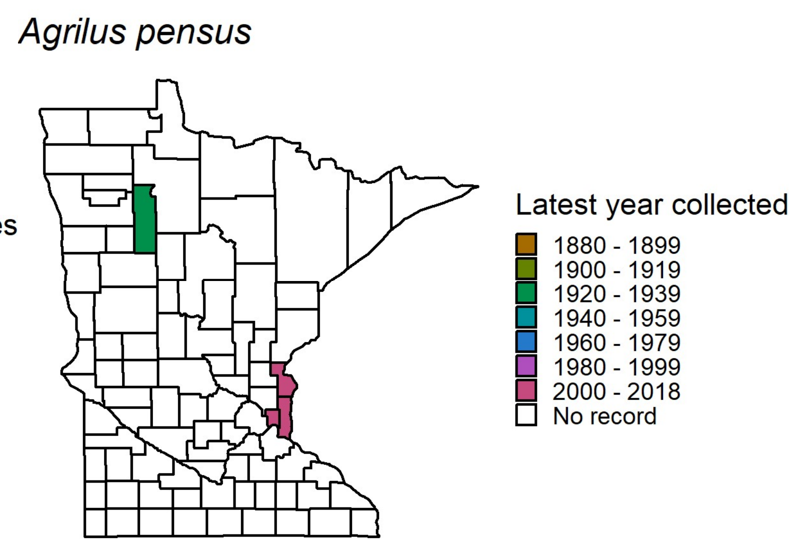

Agrilus otiosus
Number of beetles
8
6
4
2
0

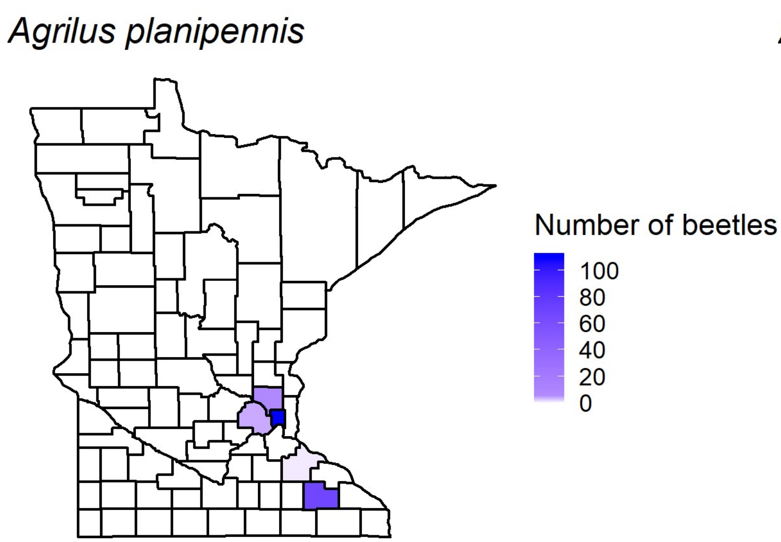

Agrilus otiosus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

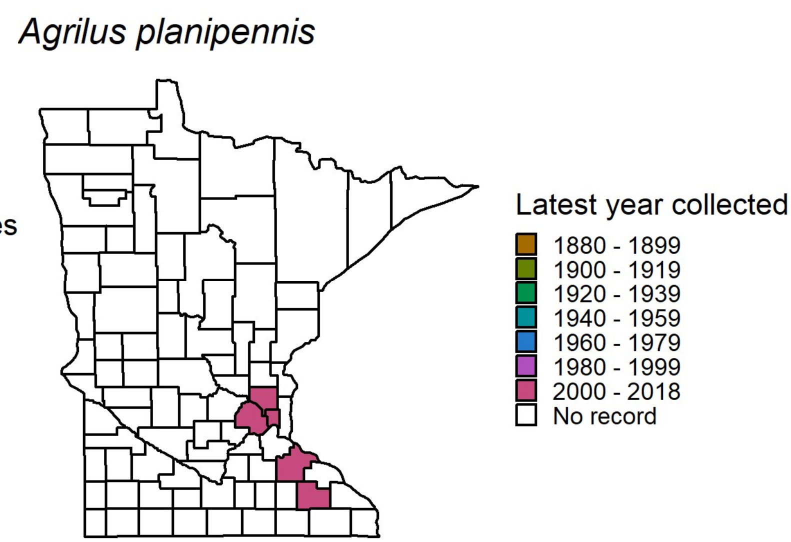

Agrilus parvus
Number of beetles
50
40
30
20
10
0

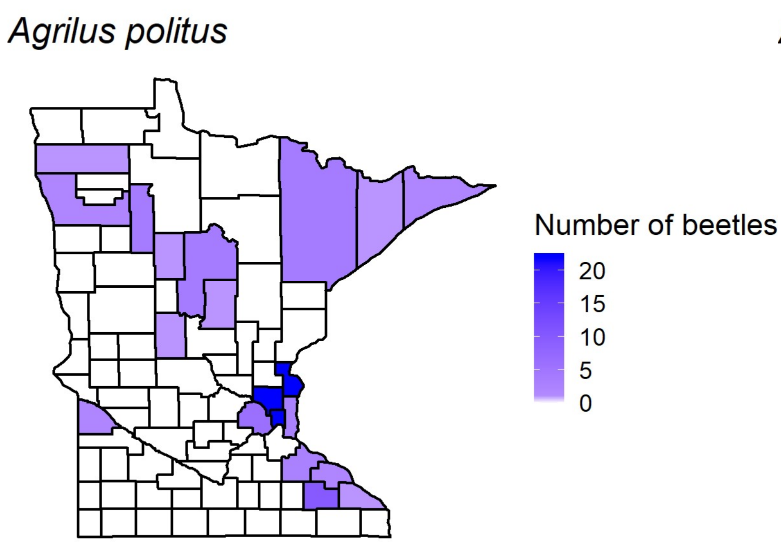

Agrilus parvus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

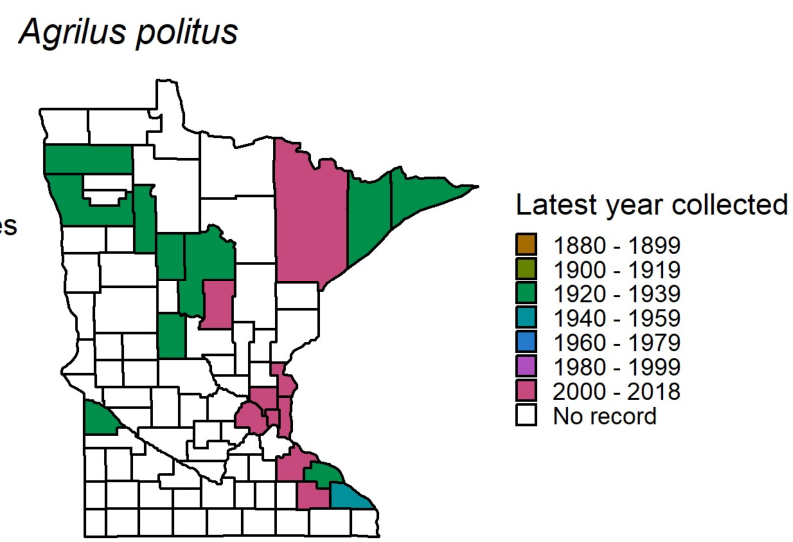

Agrilus pensus
Number of beetles
8
6
4
2
0

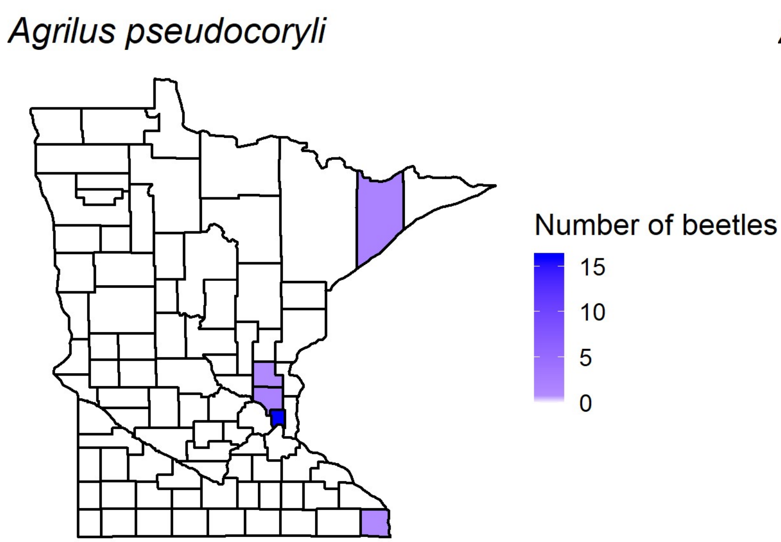

Agrilus pensus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

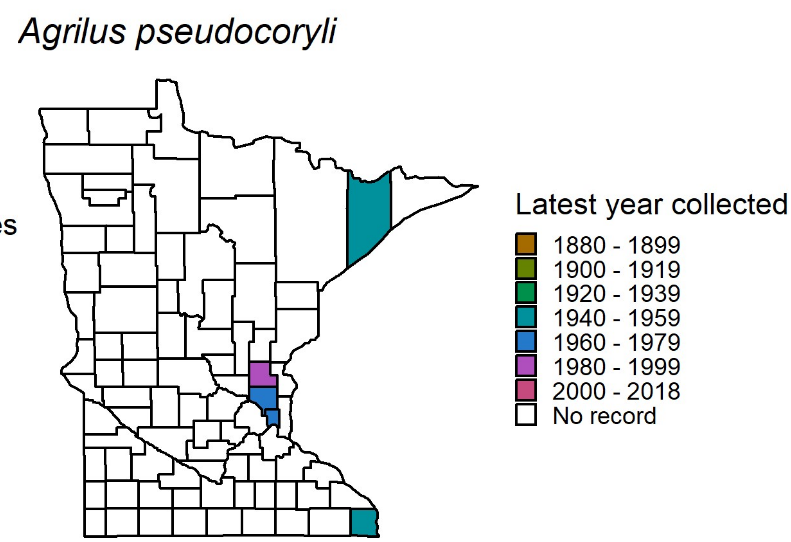

Agrilus planipennis
Number of beetles
100
80
60
40
20
0

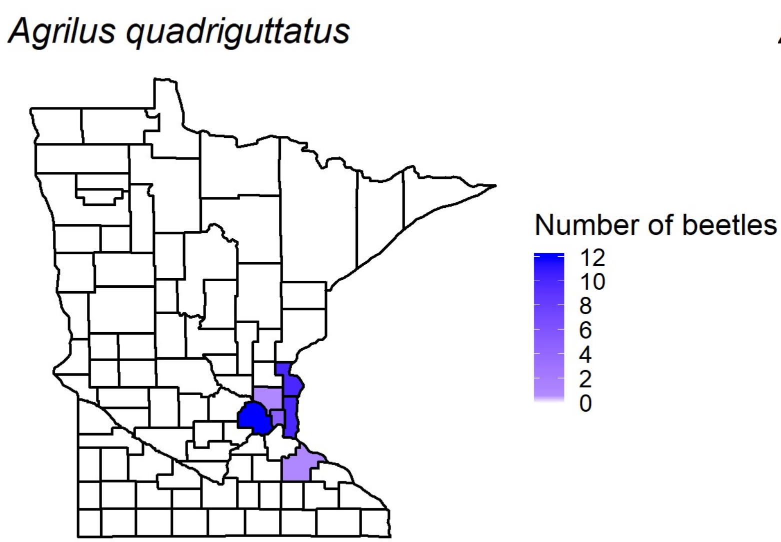

Agrilus planipennis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

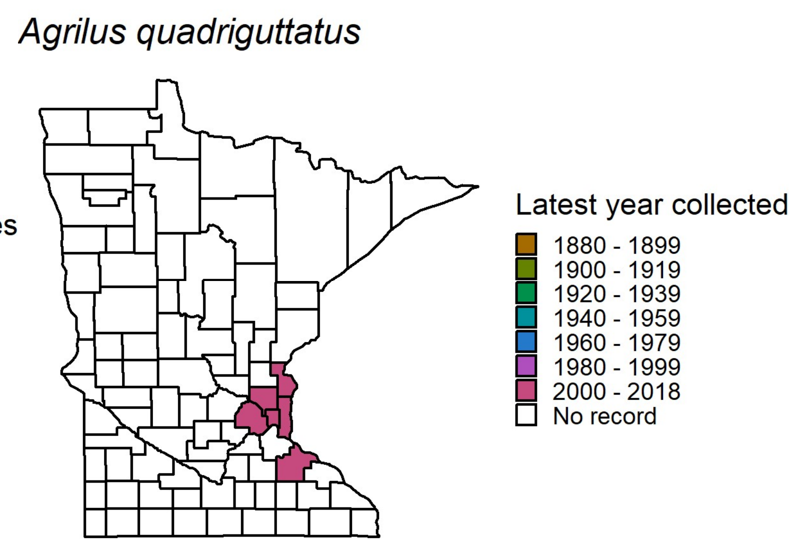

Agrilus politus
Number of beetles
20
15
10
5
0

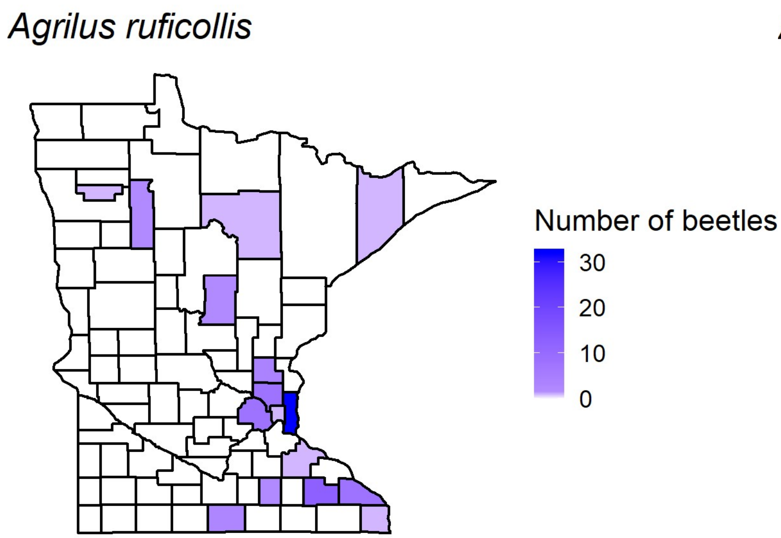

Agrilus politus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

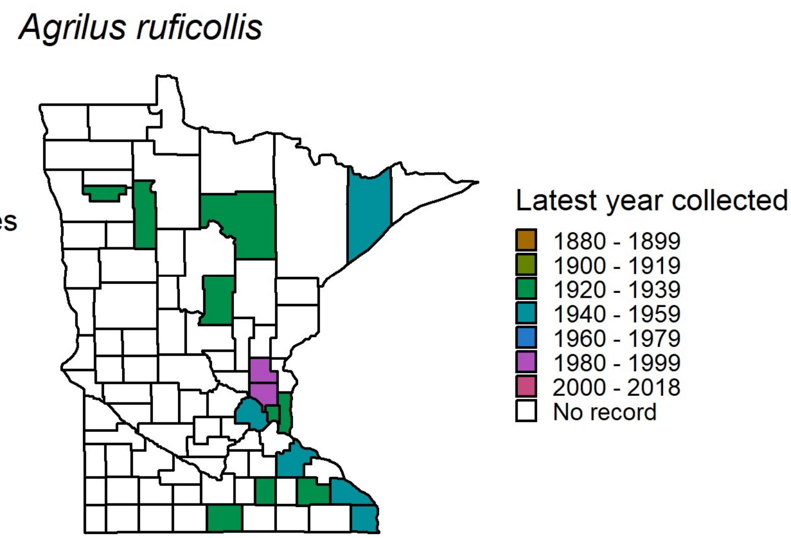

Agrilus pseudocoryli
Number of beetles
15
10
5
0

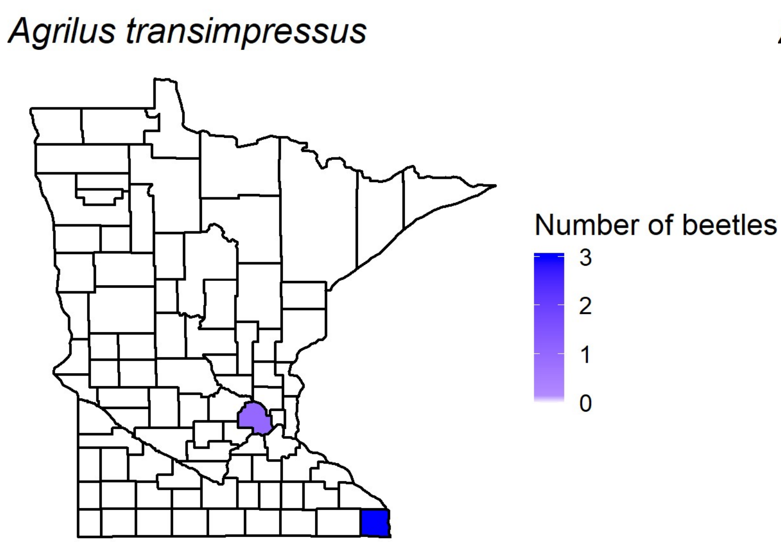

Agrilus pseudocoryli
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus quadriguttatus
Number of beetles
12
10
8
6
4
2
0

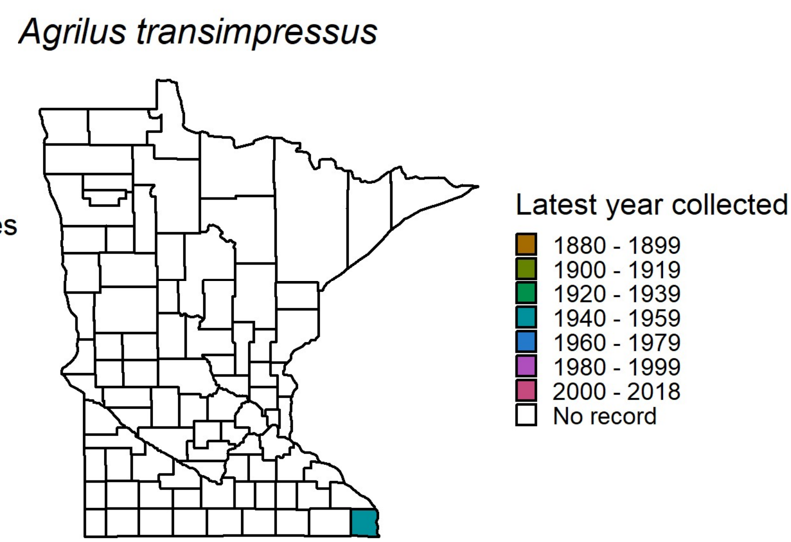

Agrilus quadriguttatus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Agrilus ruficollis
Number of beetles
30
20
10
0

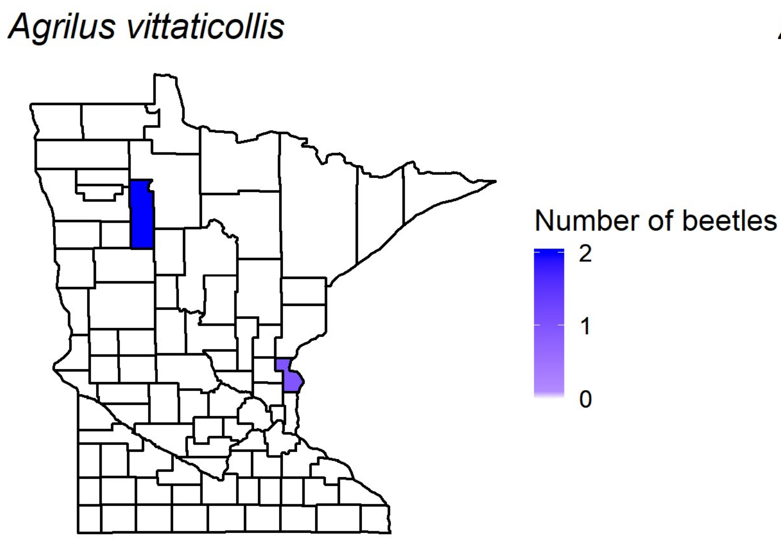

Agrilus ruficollis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

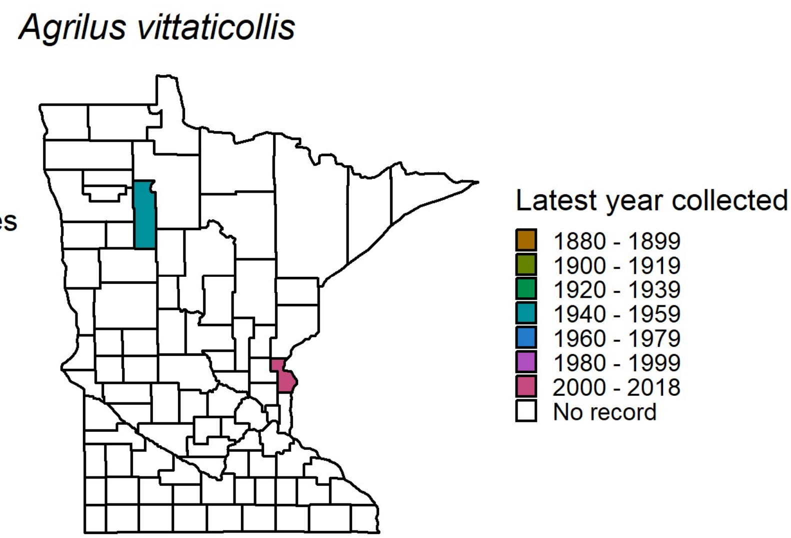


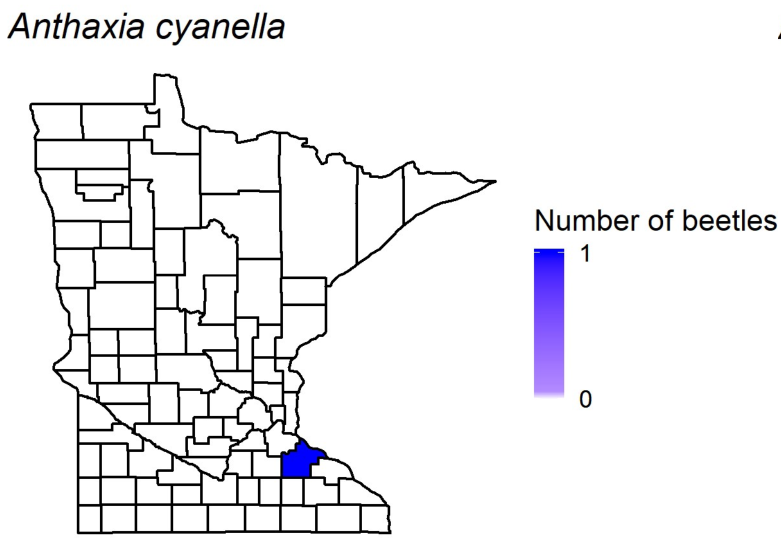
Agrilus transimpressus
Number of beetles
3
2
1
0

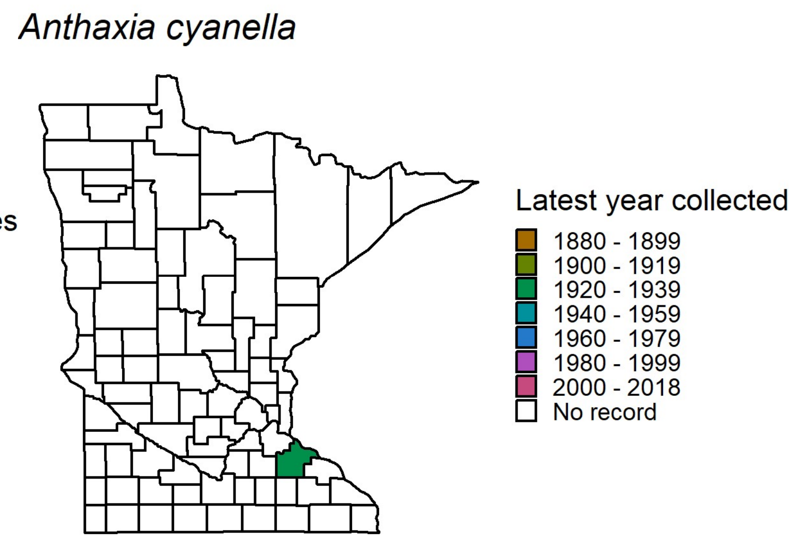


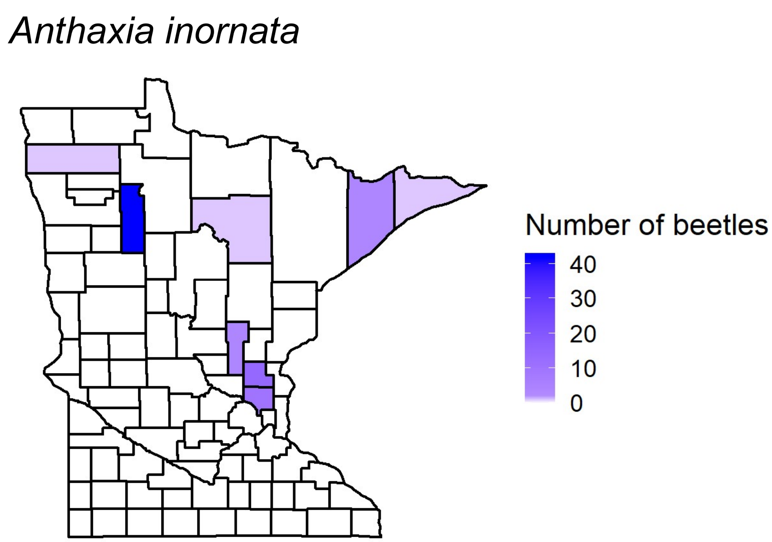
Agrilus transimpressus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

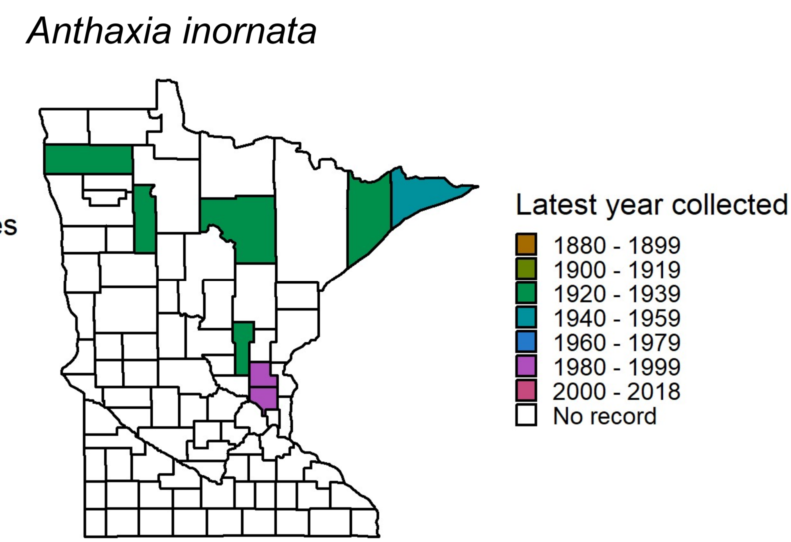

Agrilus vittaticollis
Number of beetles
2
1
0

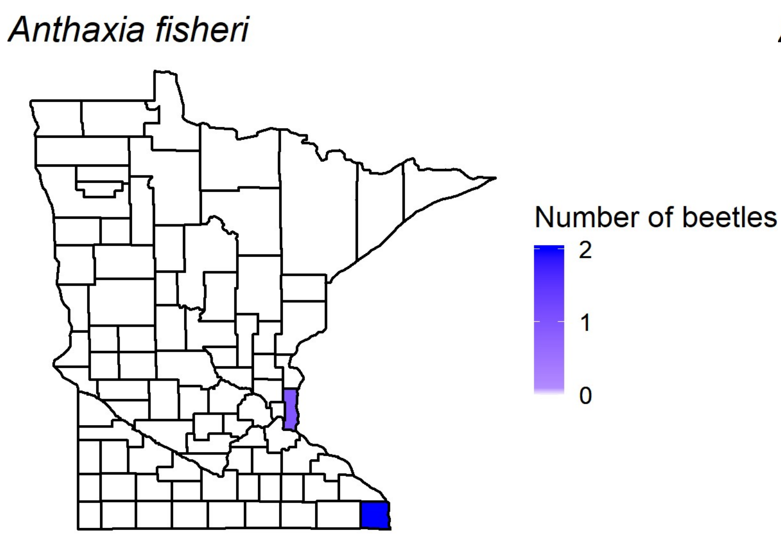

Agrilus vittaticollis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

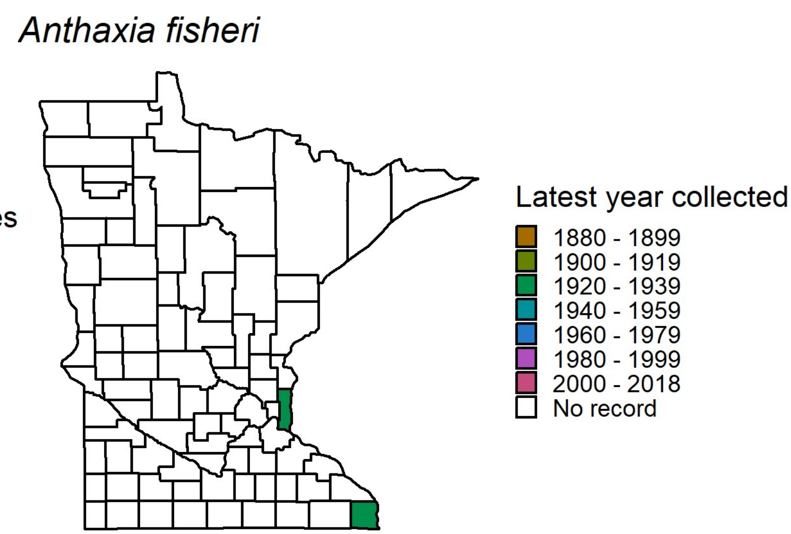

Anthaxia cyanella
Number of beetles
1
0

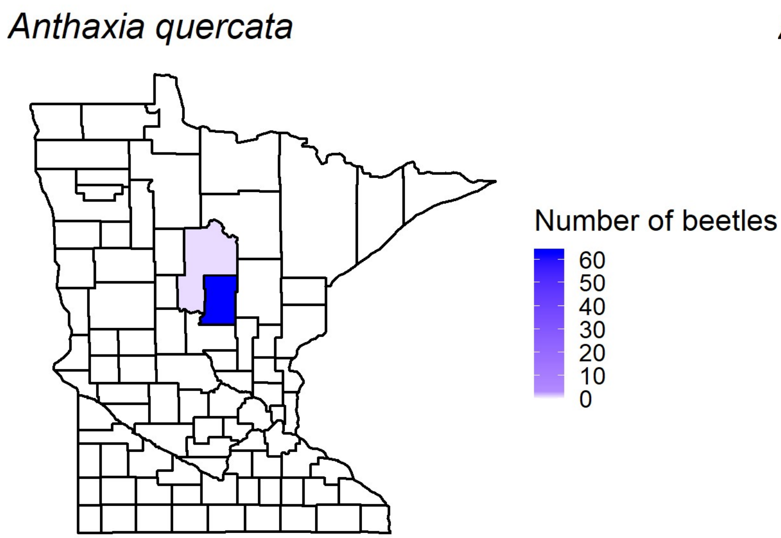

Anthaxia cyanella
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

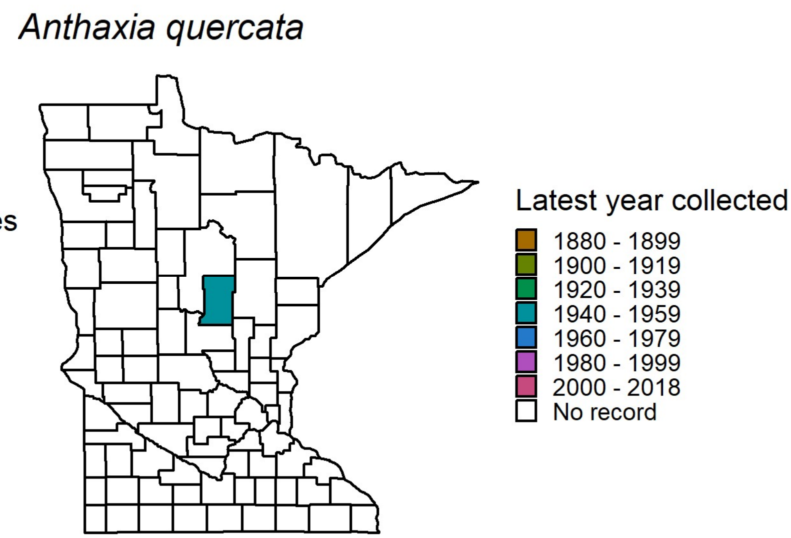

Anthaxia inornata
Number of beetles
40
30
20
10
0

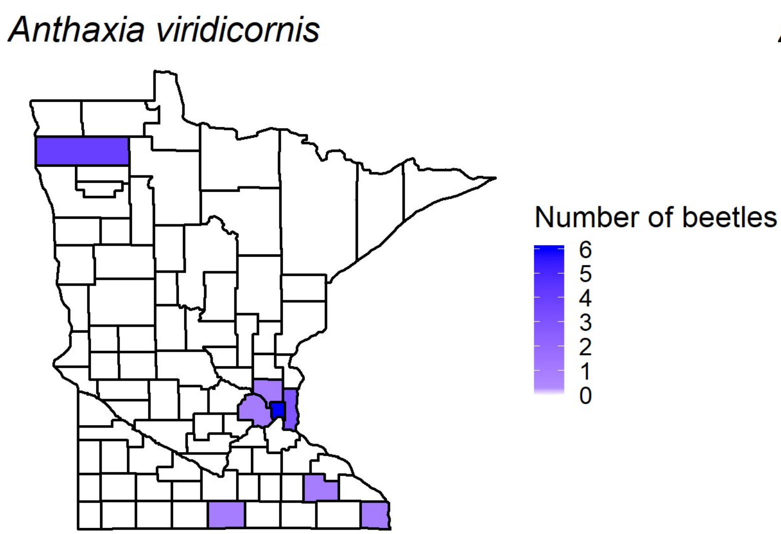

Anthaxia inornata
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Anthaxia fisheri
Number of beetles
2
1
0

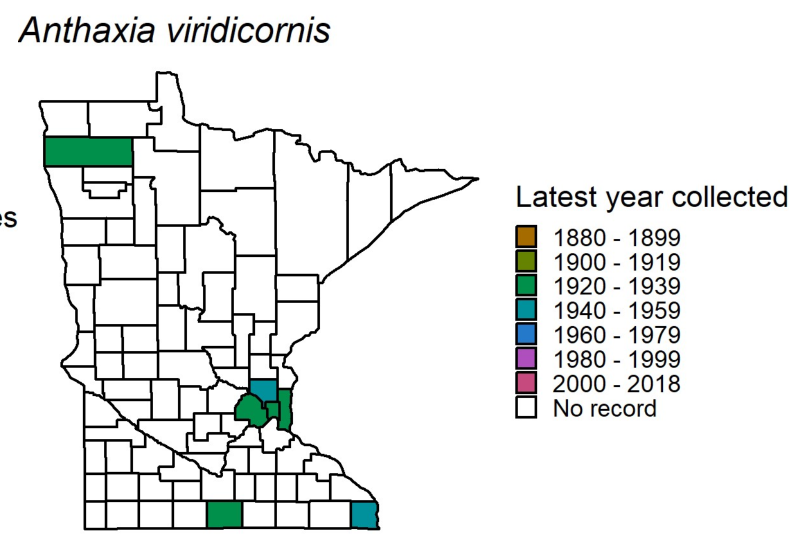

Anthaxia fisheri
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Anthaxia quercata
Number of beetles
60
50
40
30
20
10
0

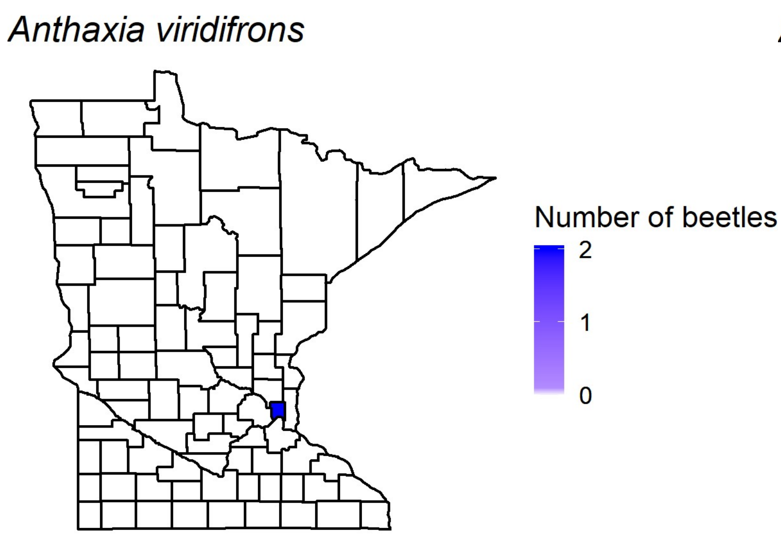

Anthaxia quercata
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record



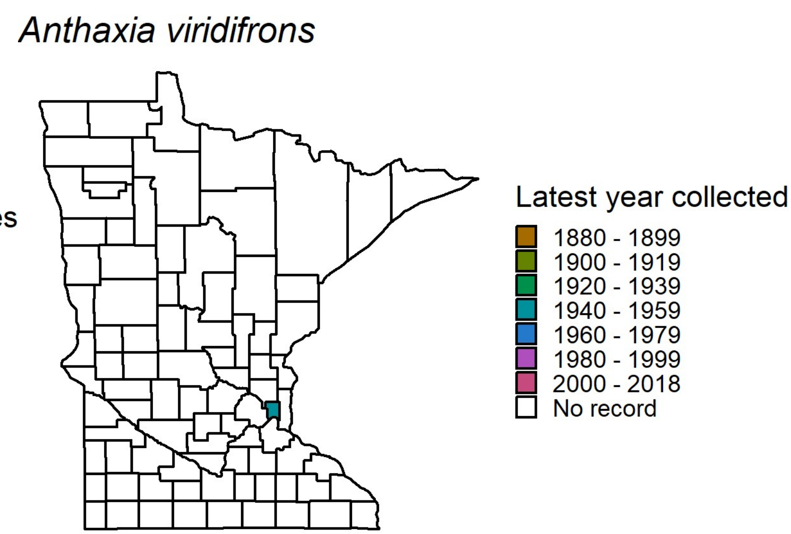
Anthaxia viridicornis
Number of beetles
6
5
4
3
2
1
0



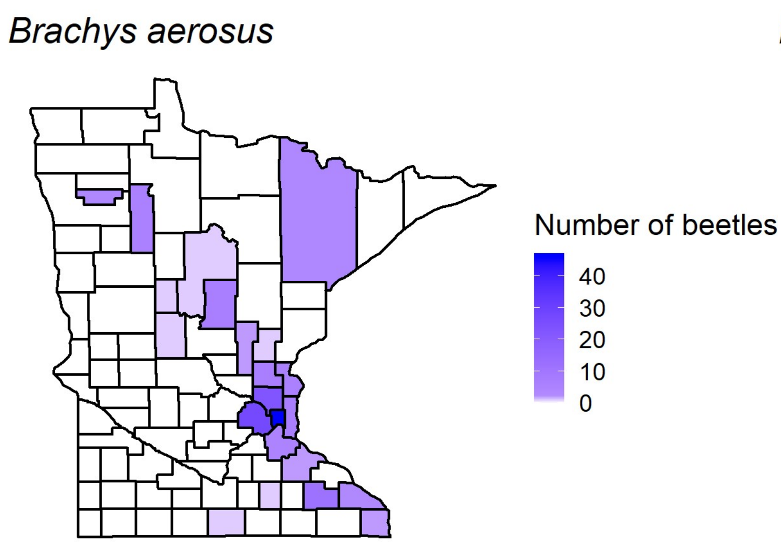
Anthaxia viridicornis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

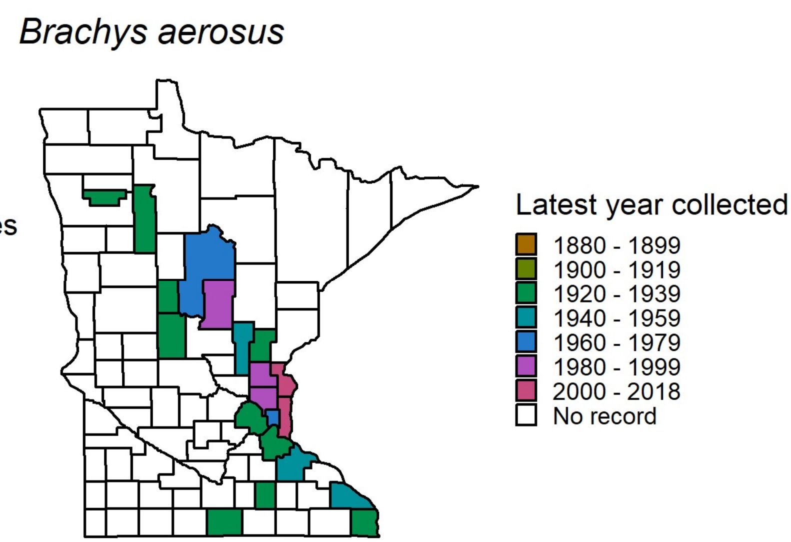


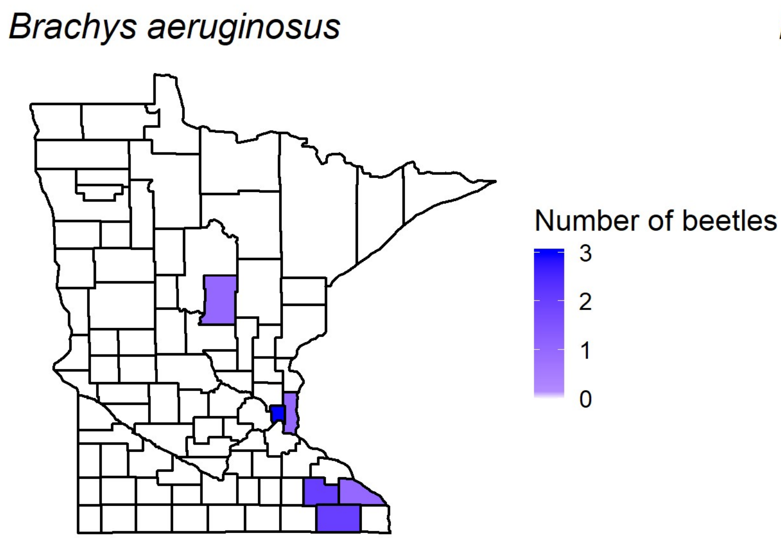
Anthaxia viridifrons
Number of beetles
2
1
0

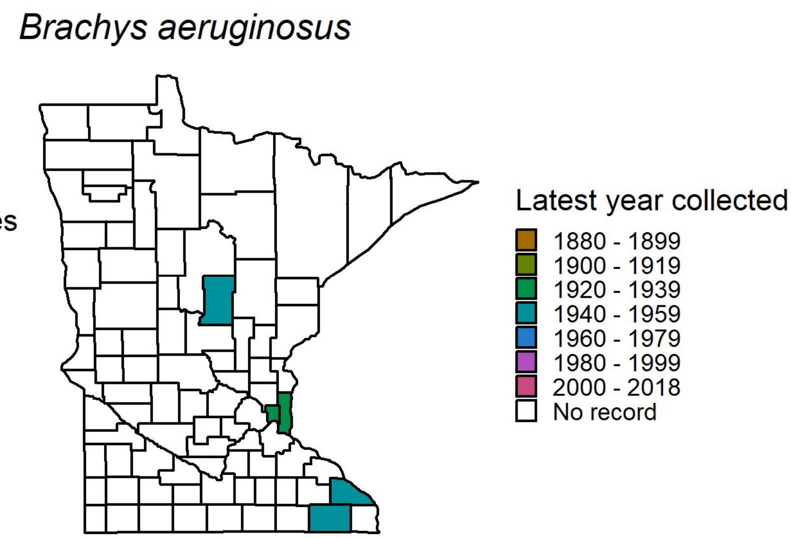


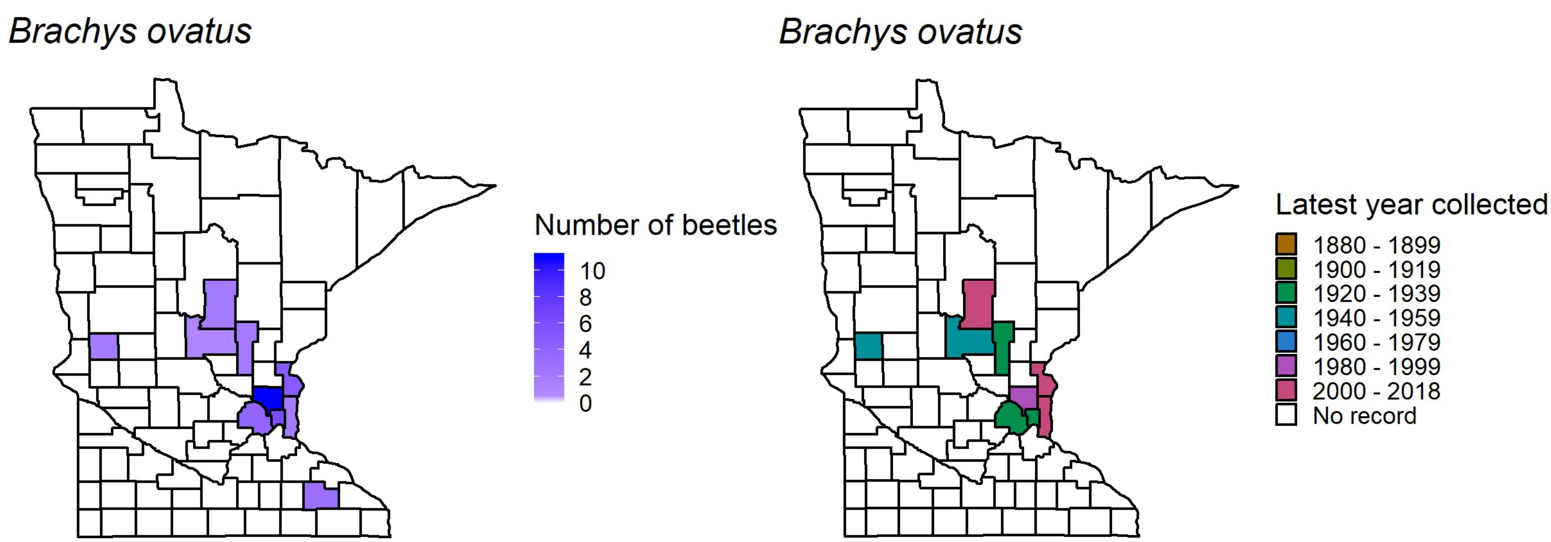
Anthaxia viridifrons
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

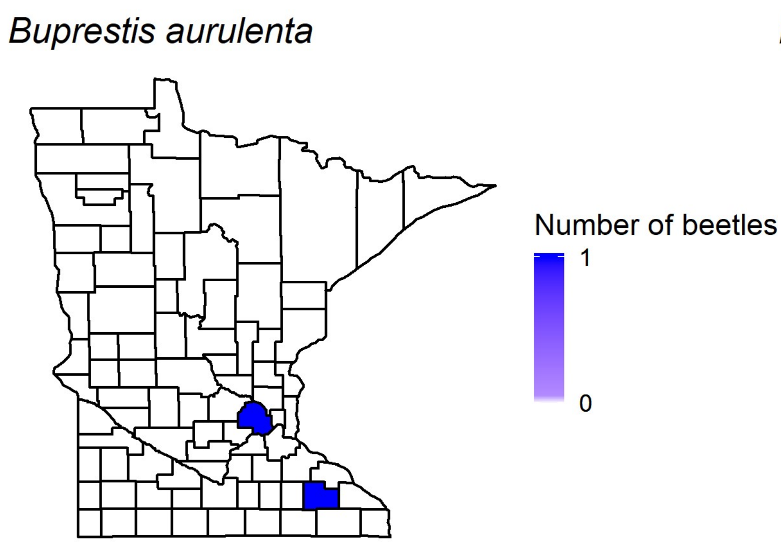

Brachys aerosus
Number of beetles
40
30
20
10
0

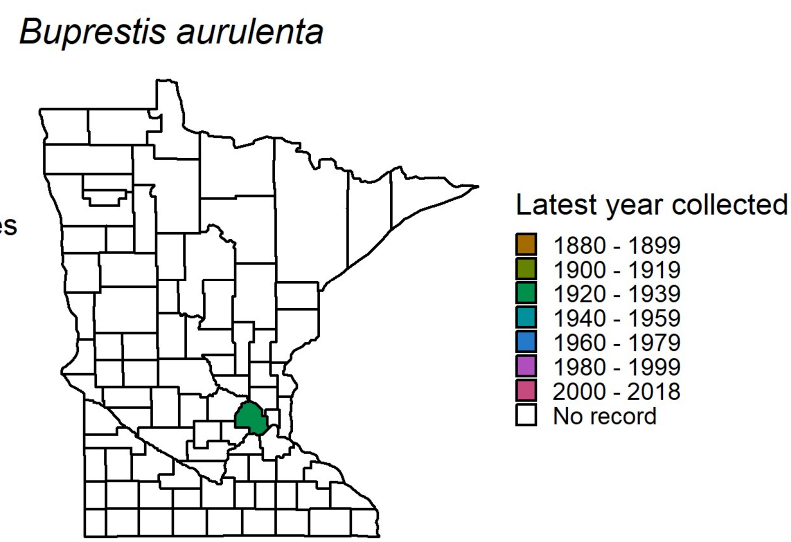

Brachys aerosus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

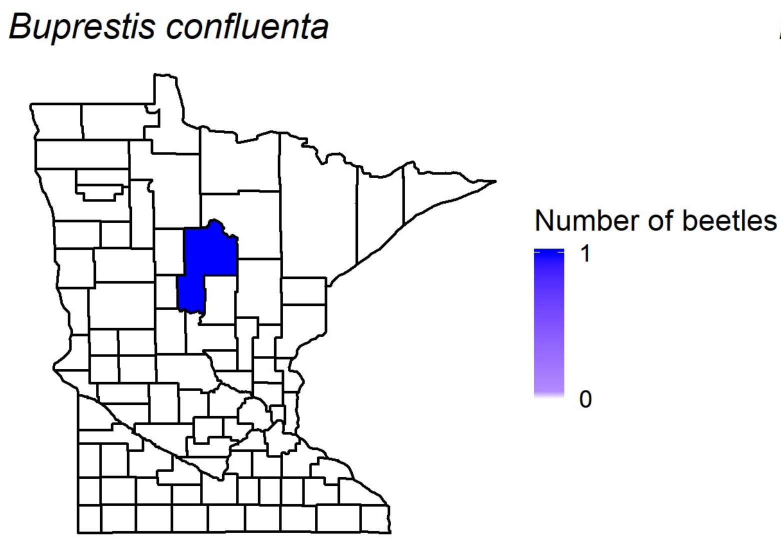

Brachys aeruginosus
Number of beetles
3
2
1
0

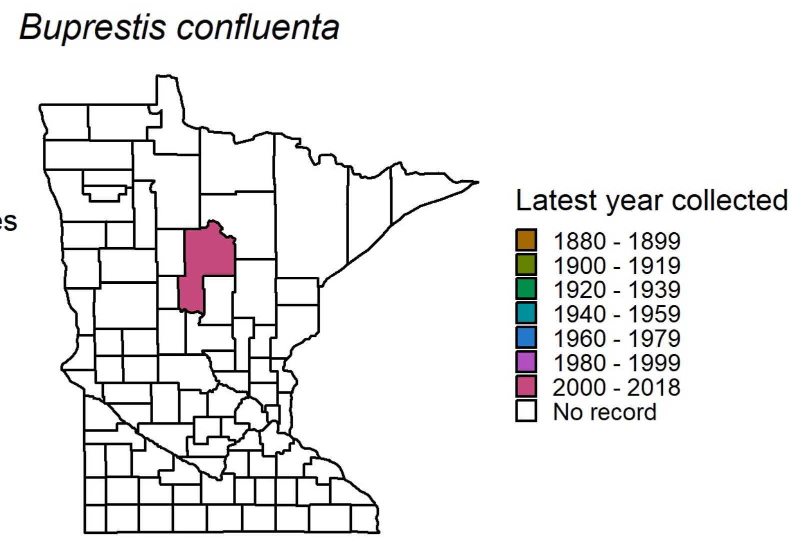

Brachys aeruginosus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

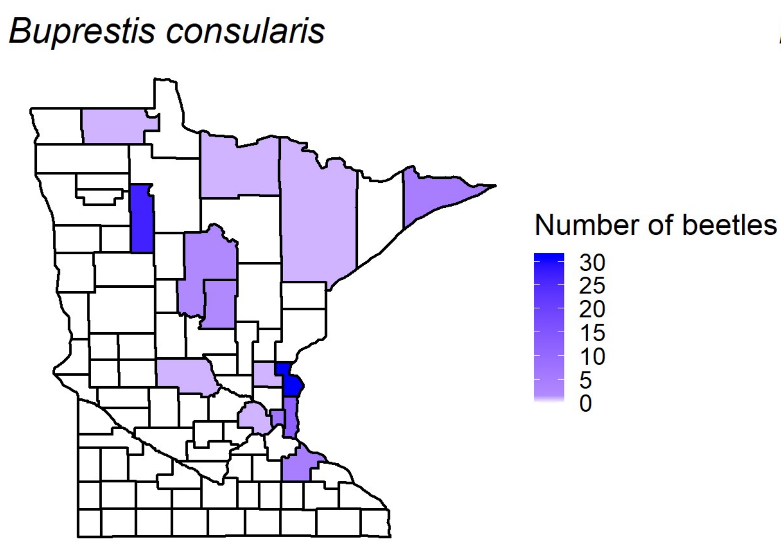

Brachys ovatus
Number of beetles
10
8
6
4
2
0
Brachys ovatus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

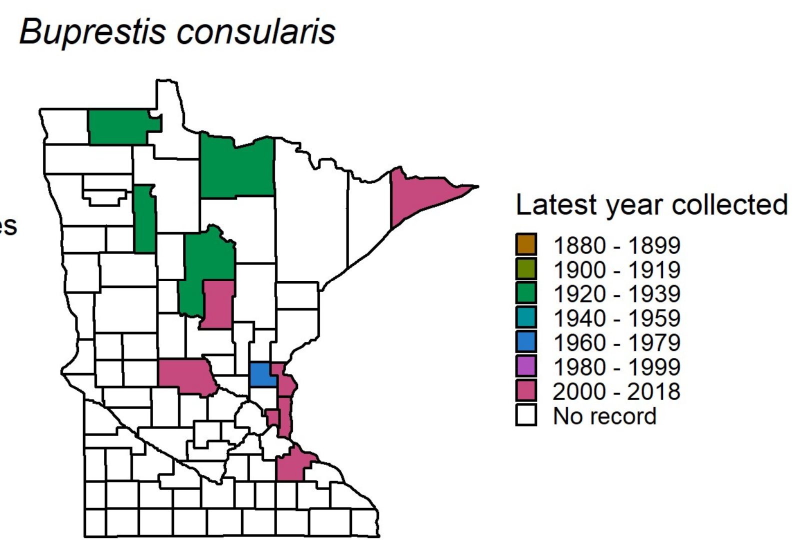

Buprestis aurulenta
Number of beetles
1
0

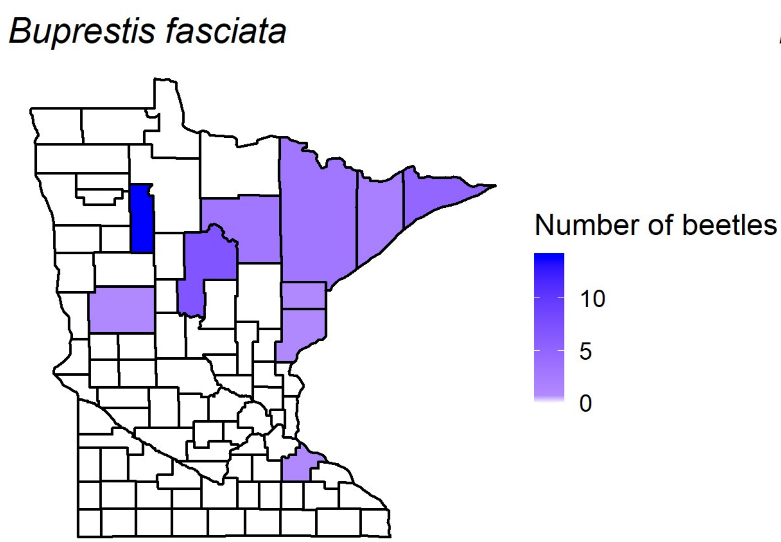

Buprestis aurulenta
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Buprestis confluenta
Number of beetles
1
0

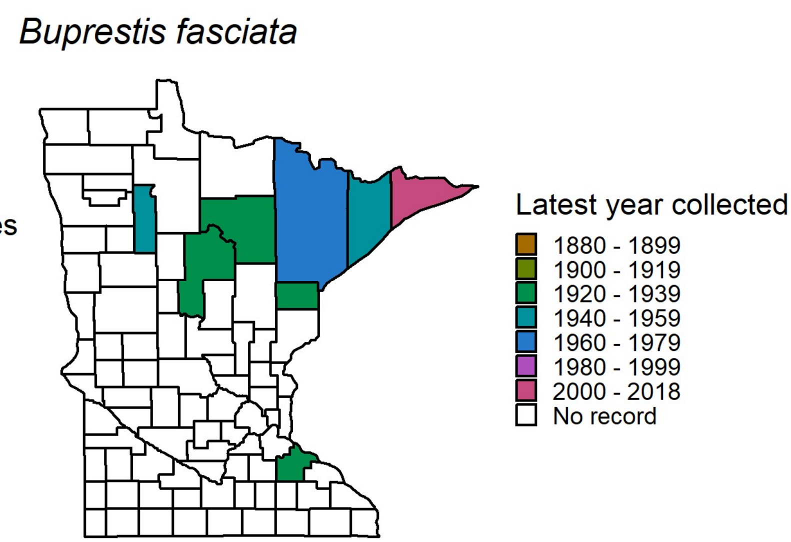

Buprestis confluenta
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Buprestis consularis
Number of beetles
30
25
20
15
10
5
0

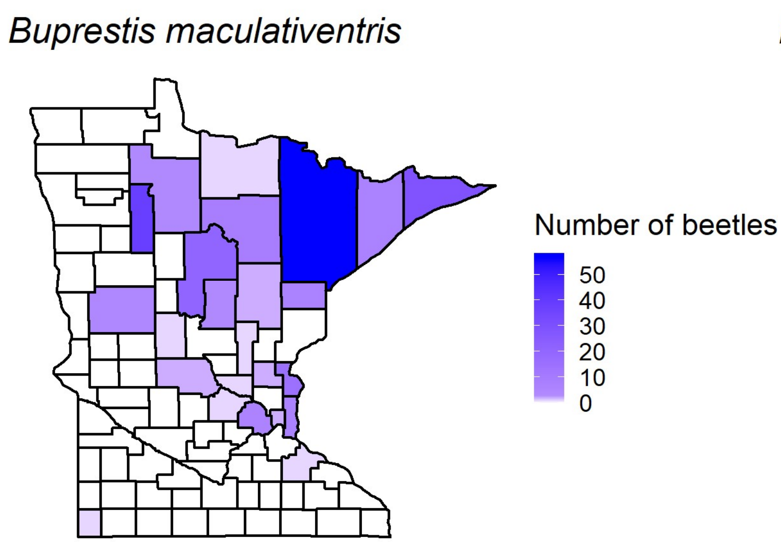

Buprestis consularis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

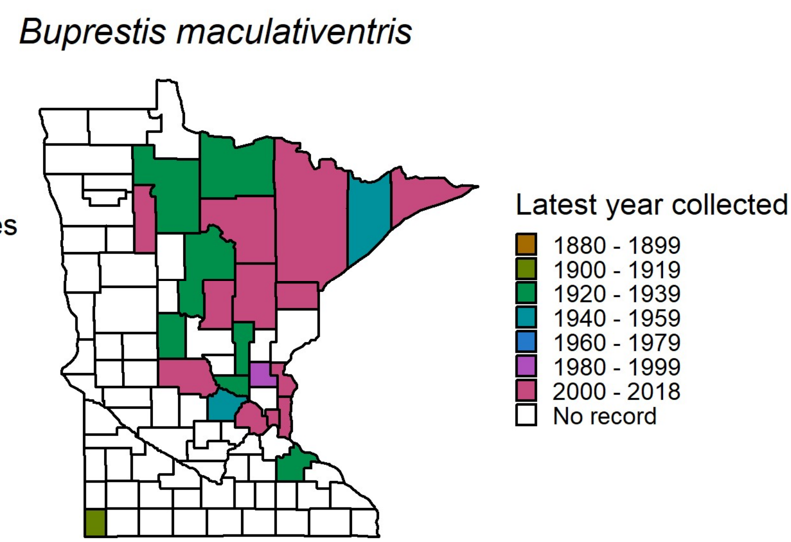


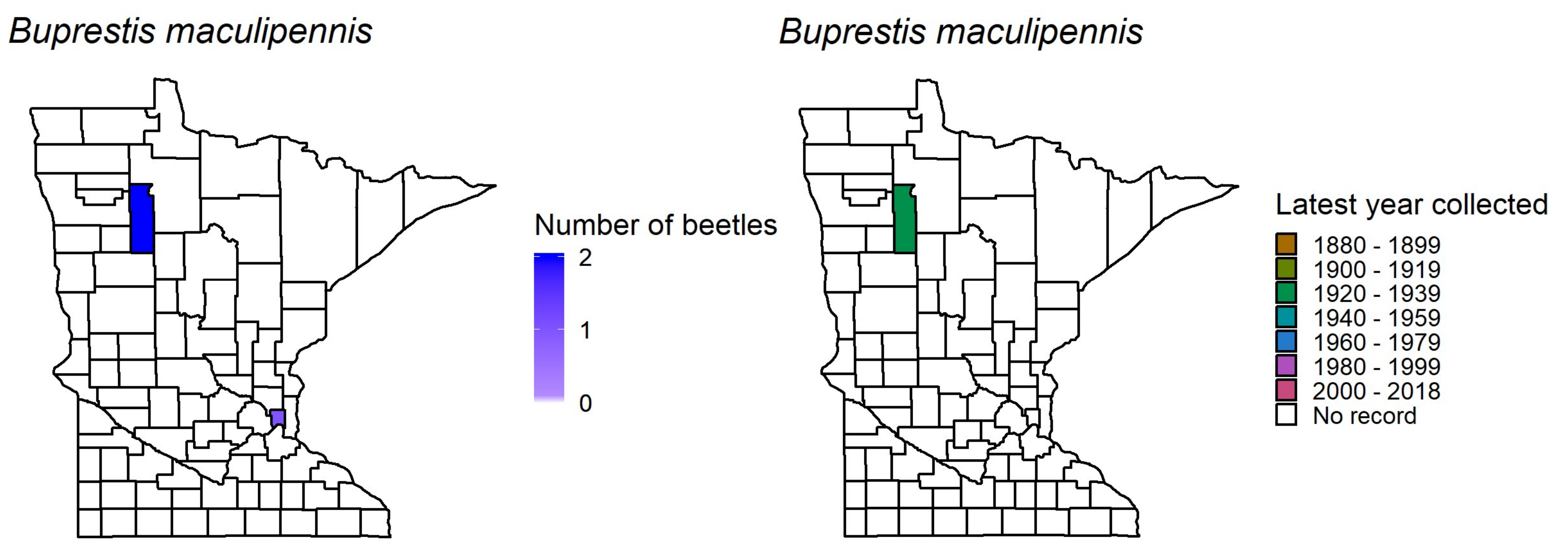
Buprestis fasciata
Number of beetles
10
5
0



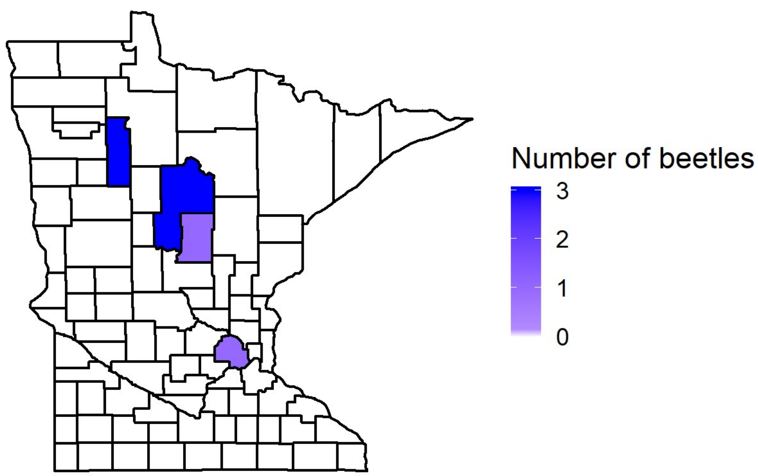
Buprestis fasciata
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Buprestis maculativentris
Number of beetles
50
40
30
20
10
0

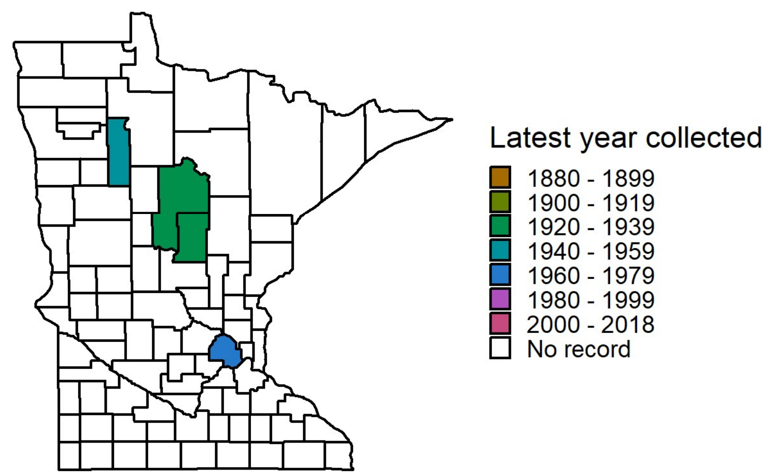

Buprestis maculativentris
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

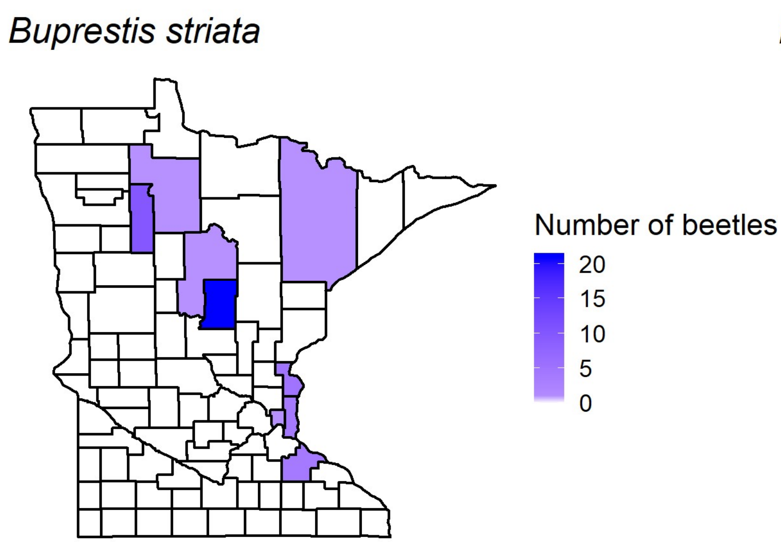

Buprestis maculipennis
Number of beetles
2
1
0
Buprestis maculipennis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

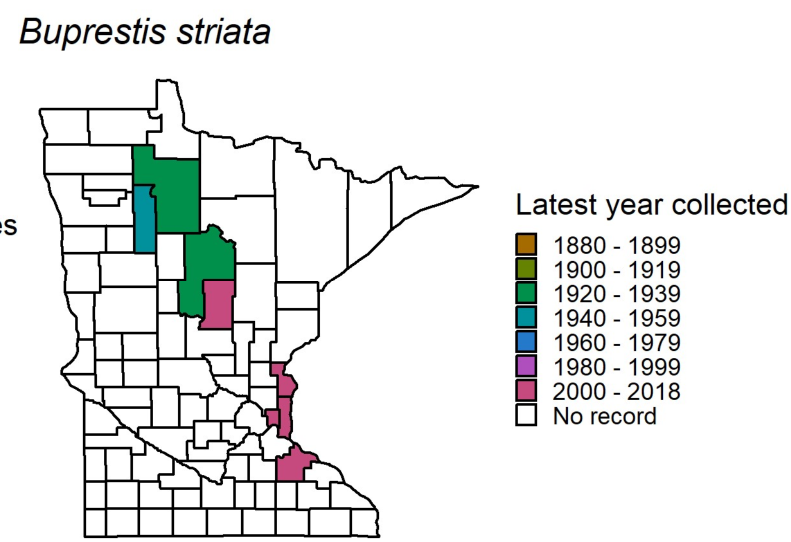
Buprestis salisburyensis

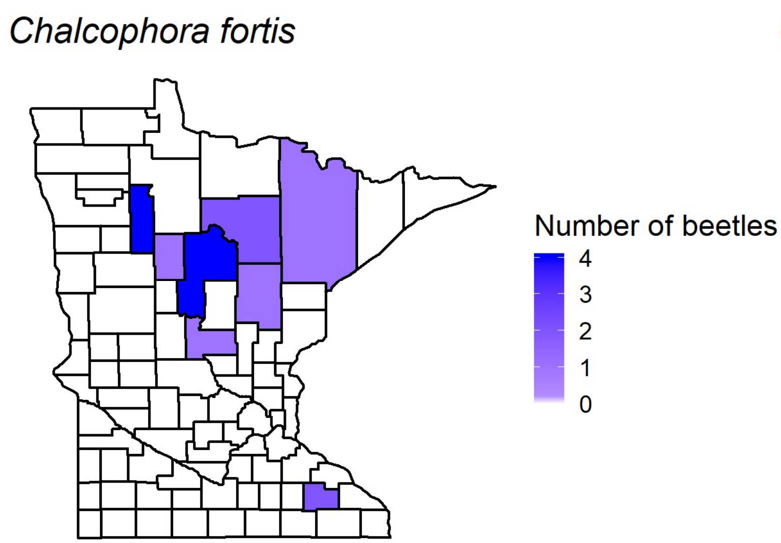


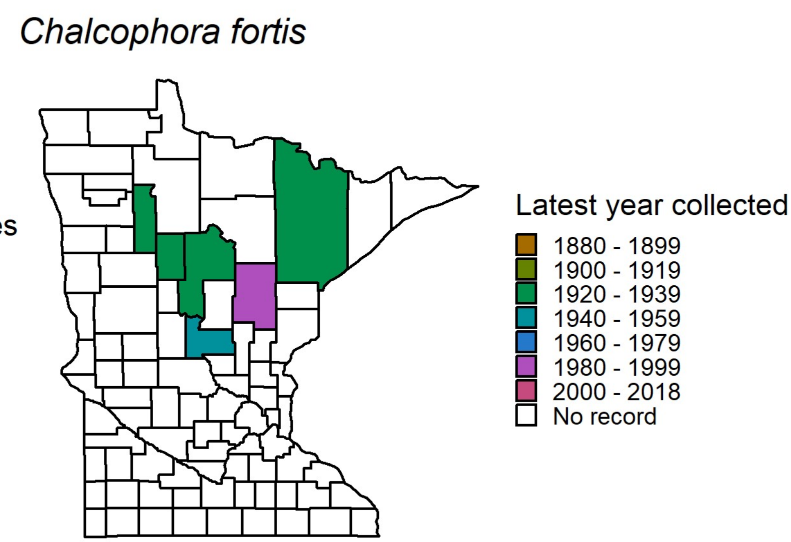
Buprestis salisburyensis

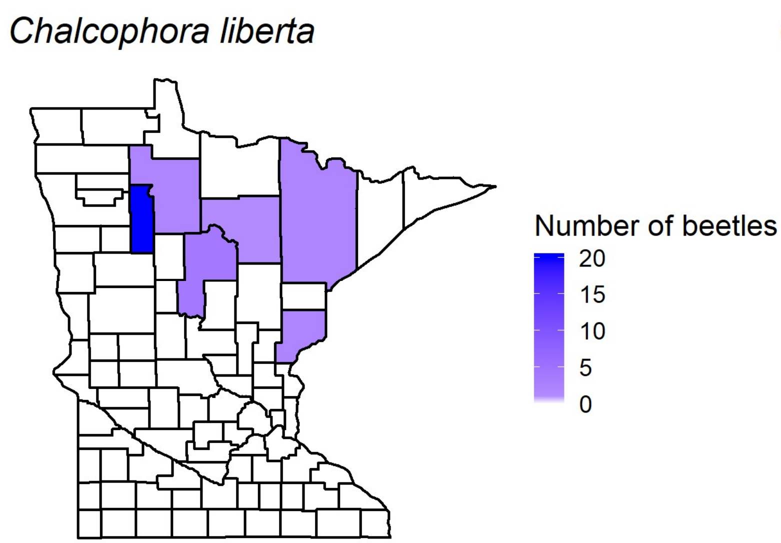


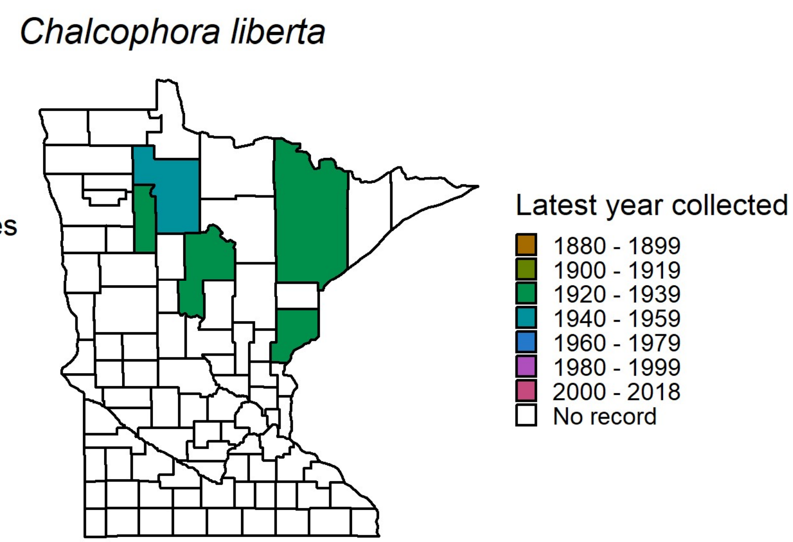

Buprestis striata
Number of beetles
20
15
10
5
0

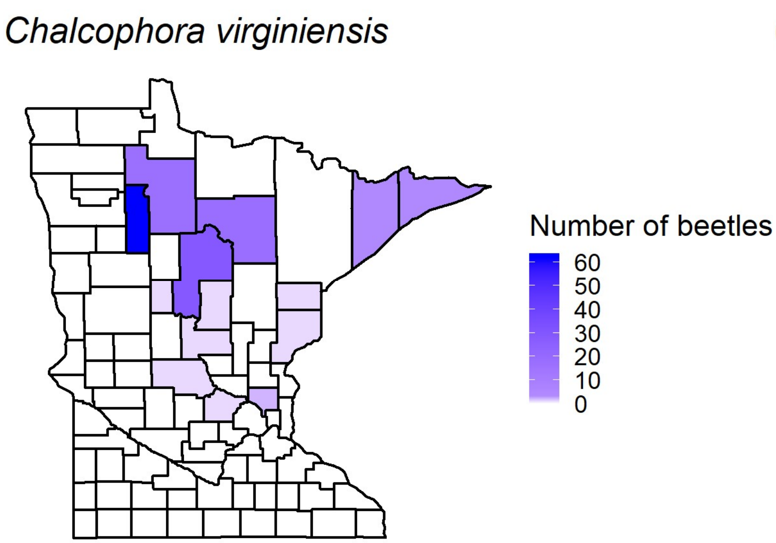

Buprestis striata
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

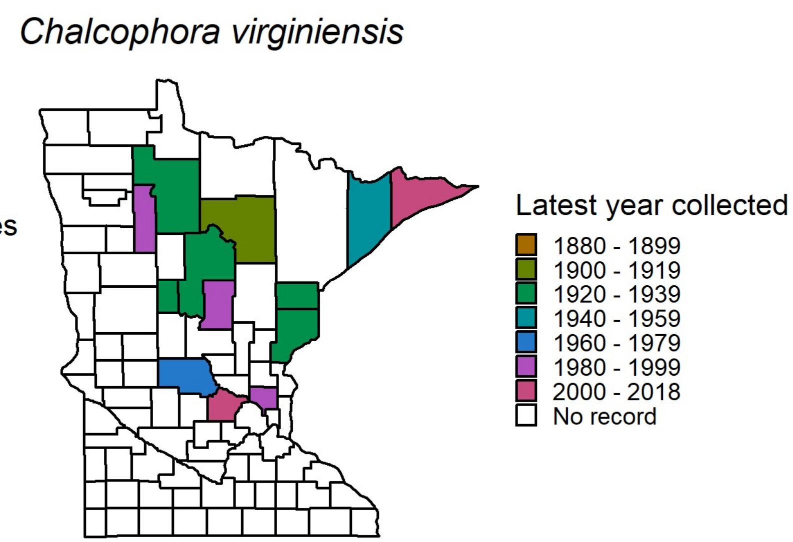

Chalcophora fortis
Number of beetles
4
3
2
1
0

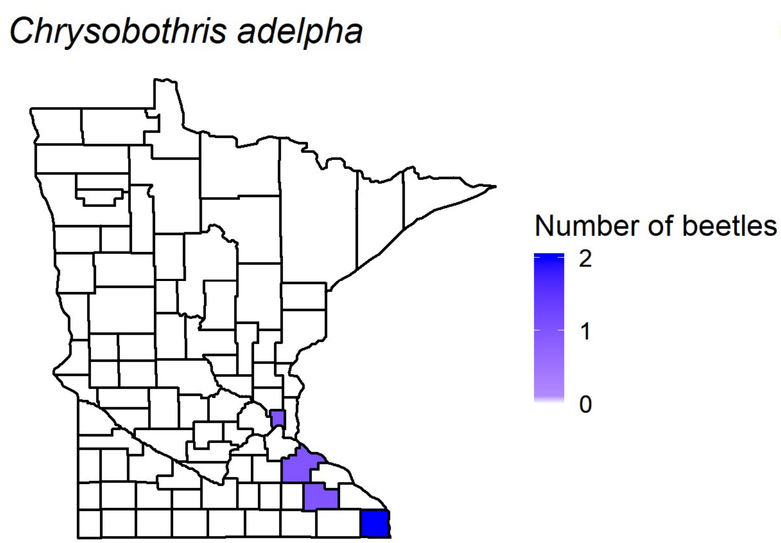

Chalcophora fortis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Chalcophora liberta
Number of beetles
20
15
10
5
0

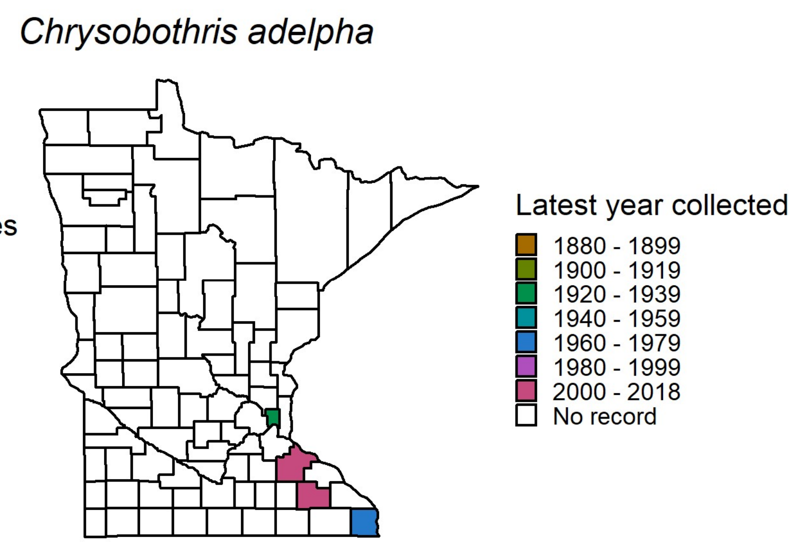

Chalcophora liberta
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Chalcophora virginiensis
Number of beetles
60
50
40
30
20
10
0

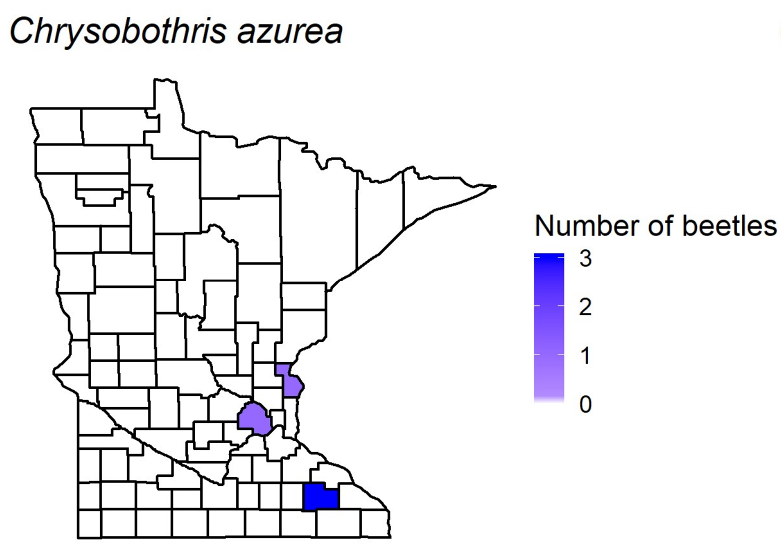

Chalcophora virginiensis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record



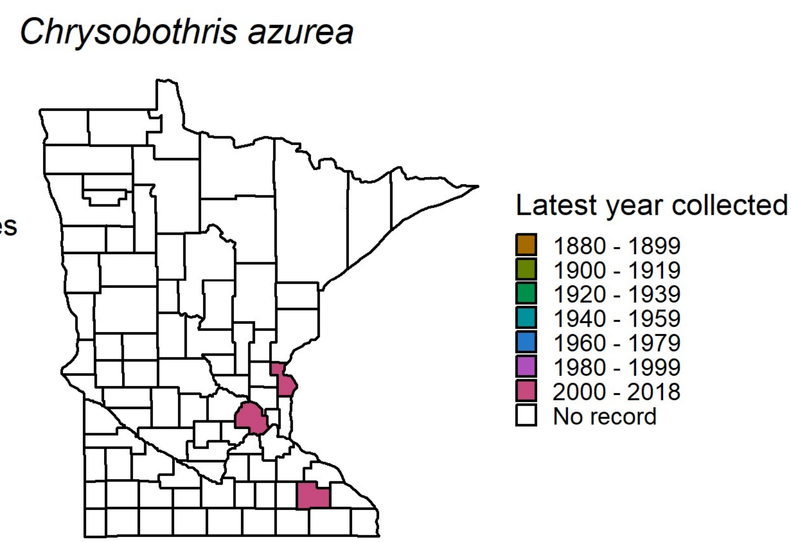
Chrysobothris adelpha
Number of beetles
2
1
0



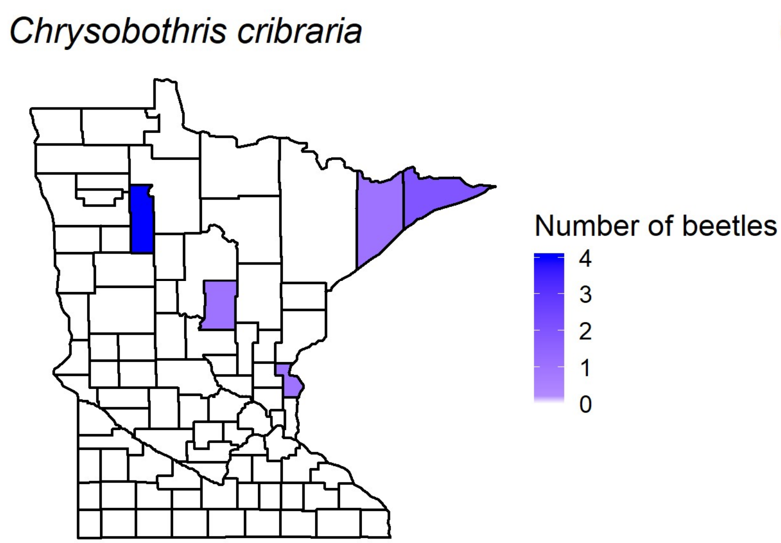
Chrysobothris adelpha
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

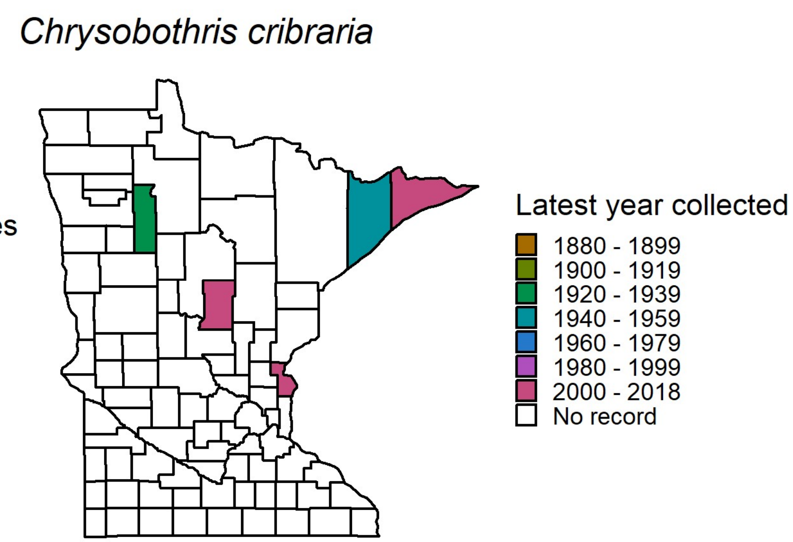


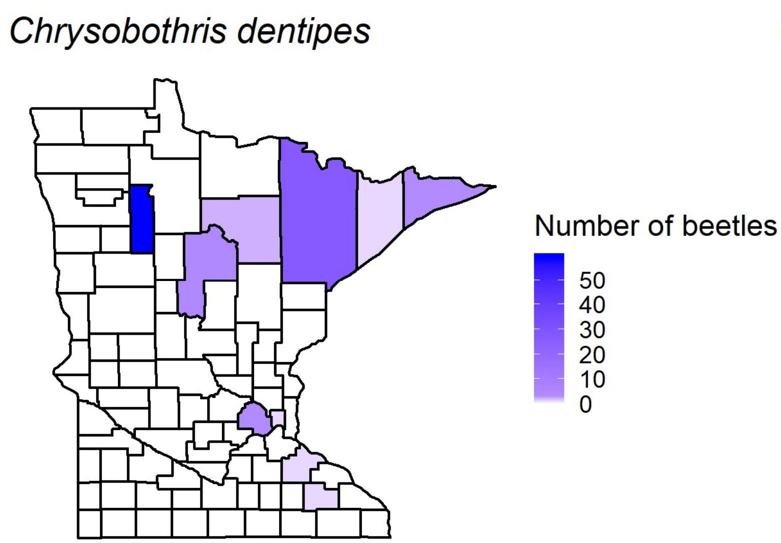
Chrysobothris azurea
Number of beetles
3
2
1
0

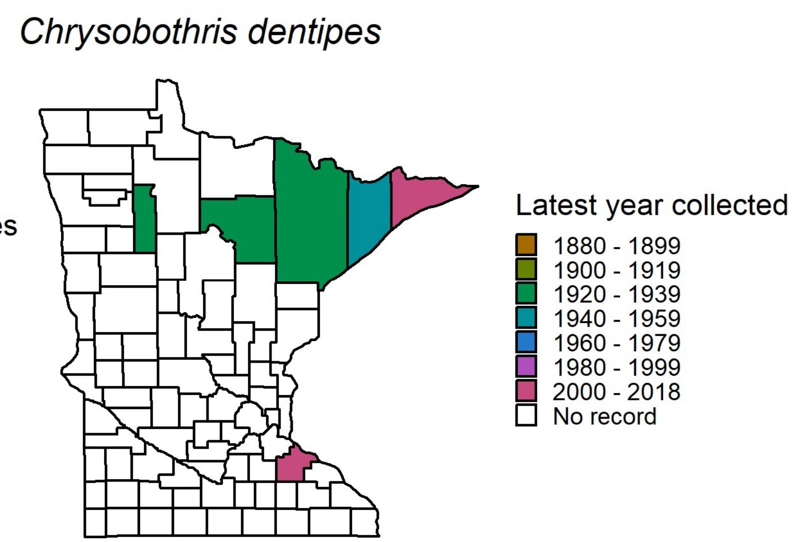


Chrysobothris azurea
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

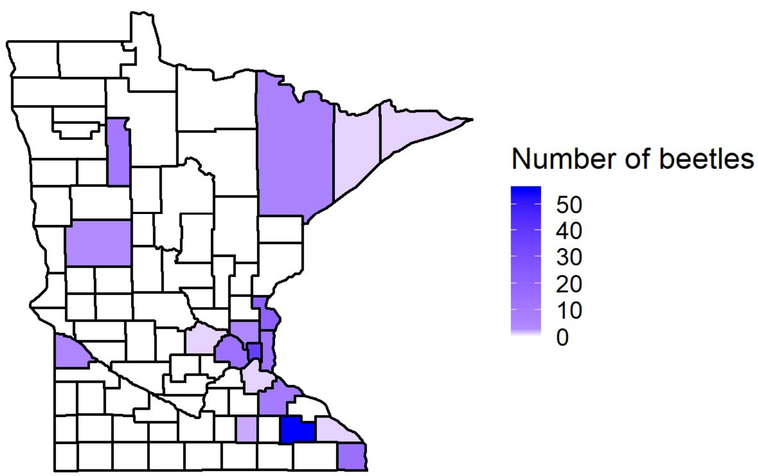

Chrysobothris cribraria
Number of beetles
4
3
2
1
0


Chrysobothris cribraria
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

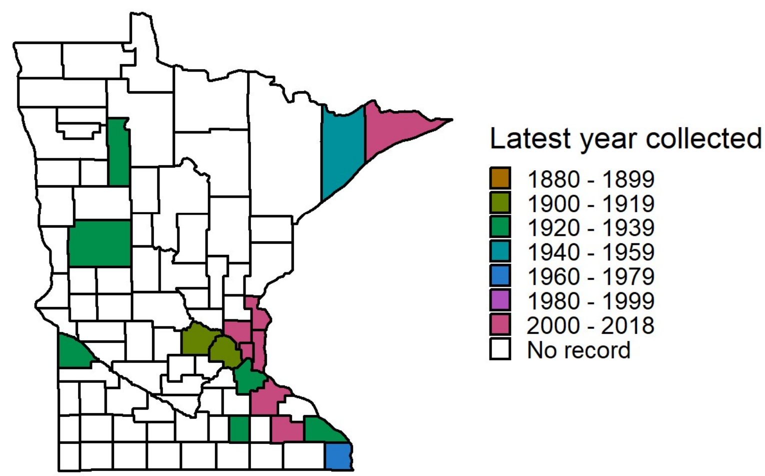

Chrysobothris dentipes
Number of beetles
50
40
30
20
10
0

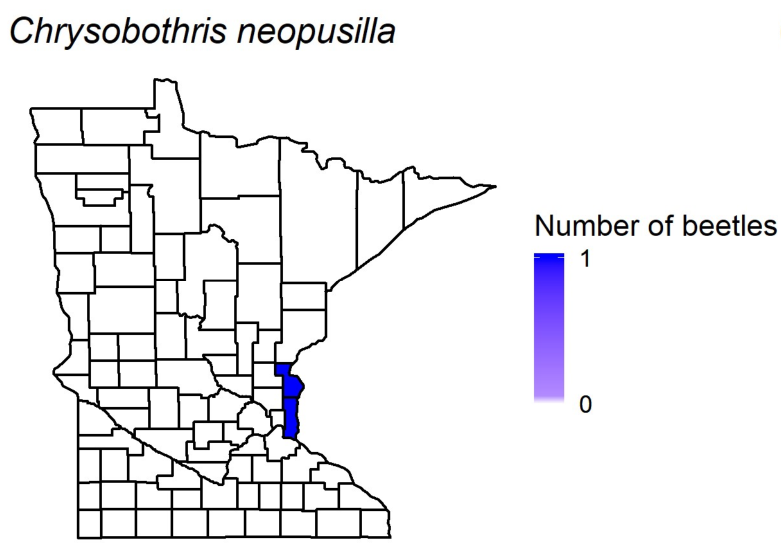

Chrysobothris dentipes
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

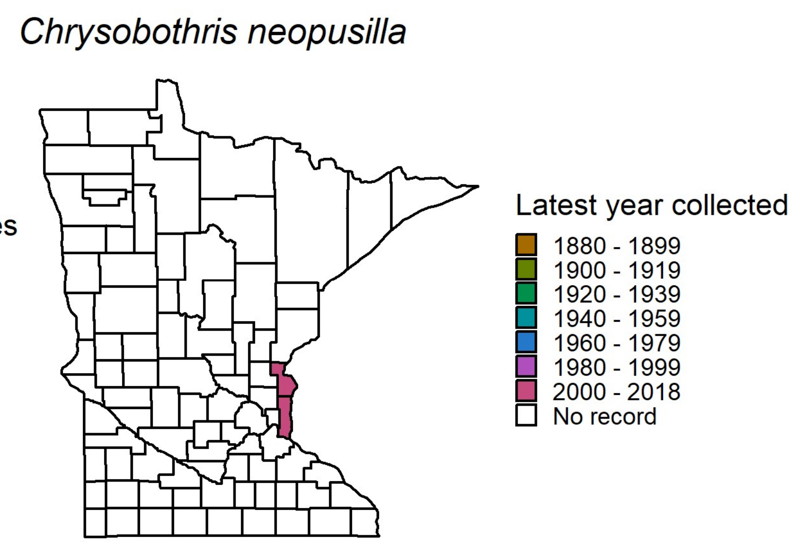
Chrysobothris femorata

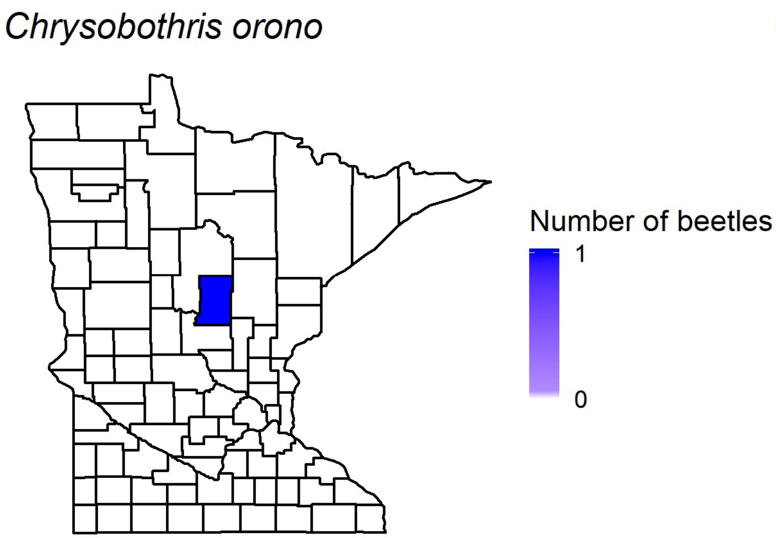


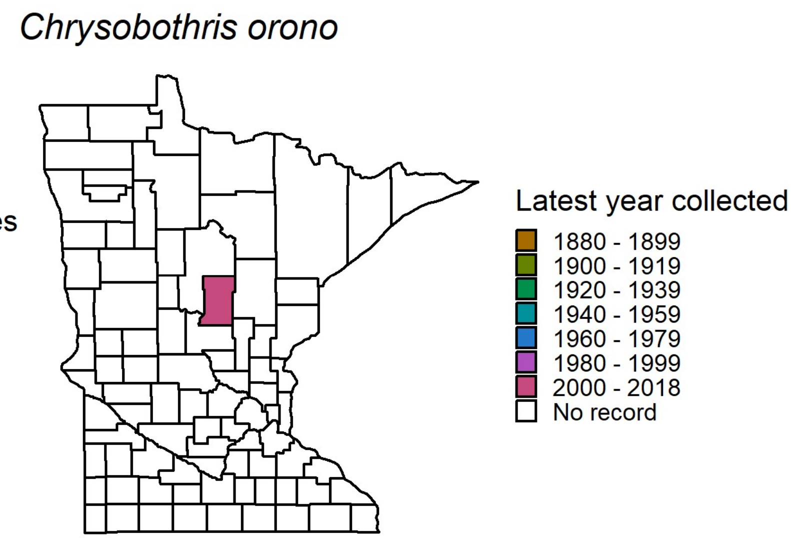
Chrysobothris femorata

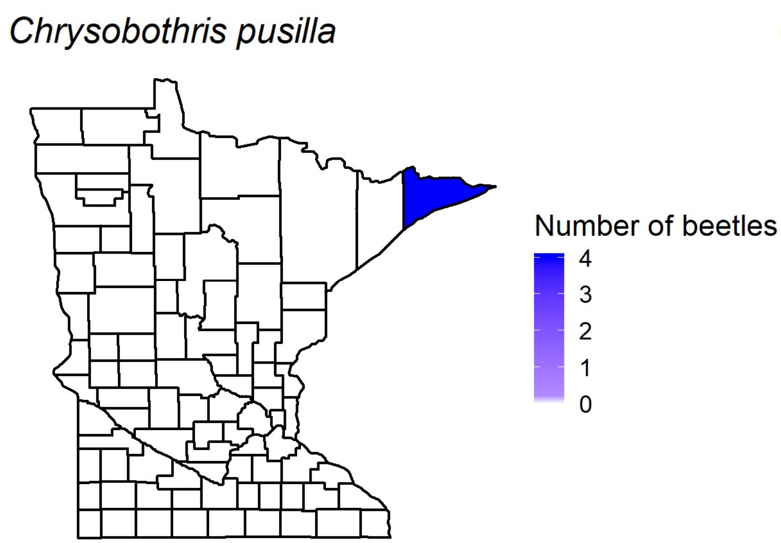



Chrysobothris neopusilla
Number of beetles
1
0

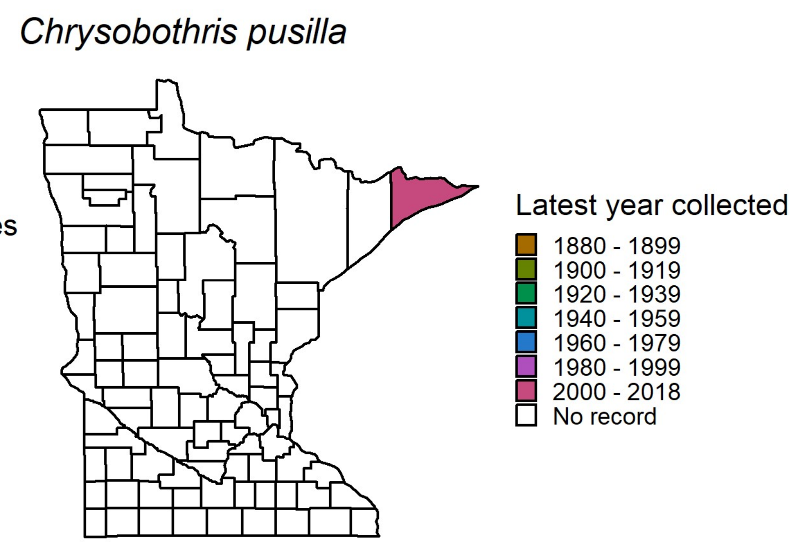

Chrysobothris neopusilla
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Chrysobothris orono
Number of beetles
1
0

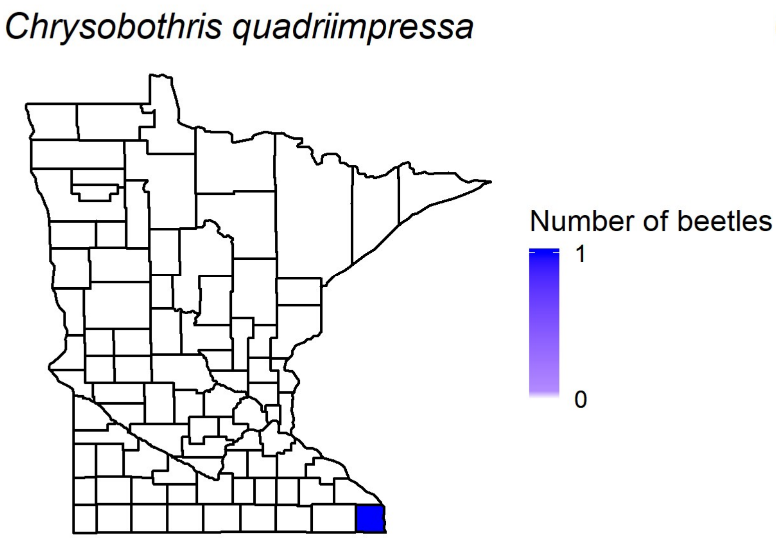

Chrysobothris orono
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

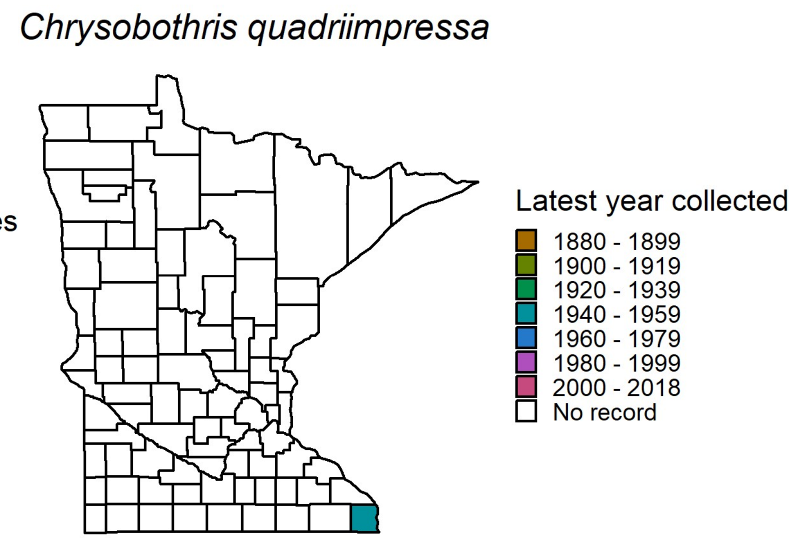


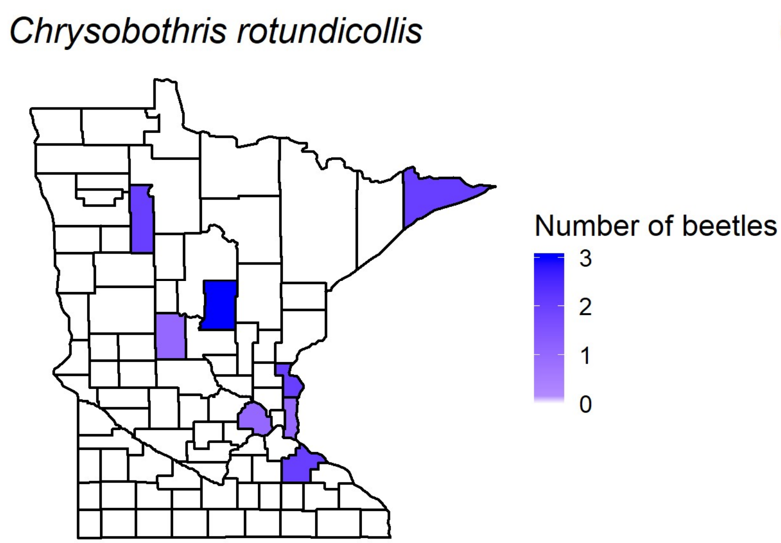
Chrysobothris pusilla
Number of beetles
4
3
2
1
0

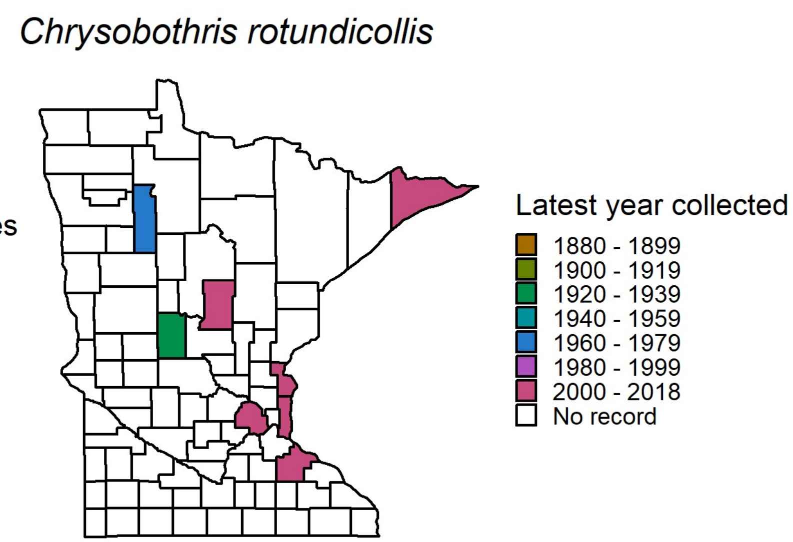


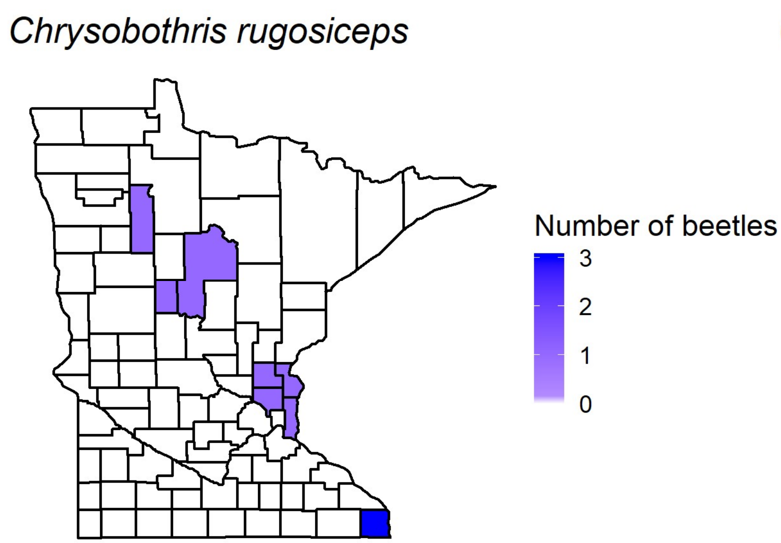
Chrysobothris pusilla
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

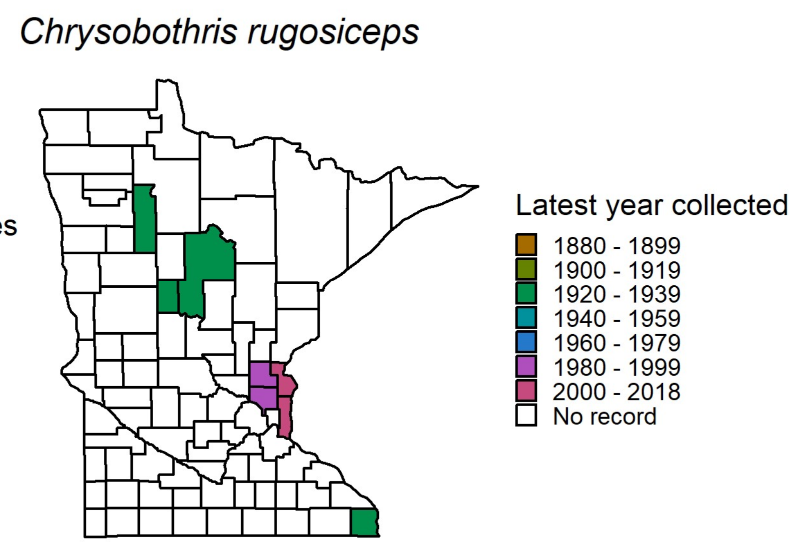

Chrysobothris quadriimpressa
Number of beetles
1
0

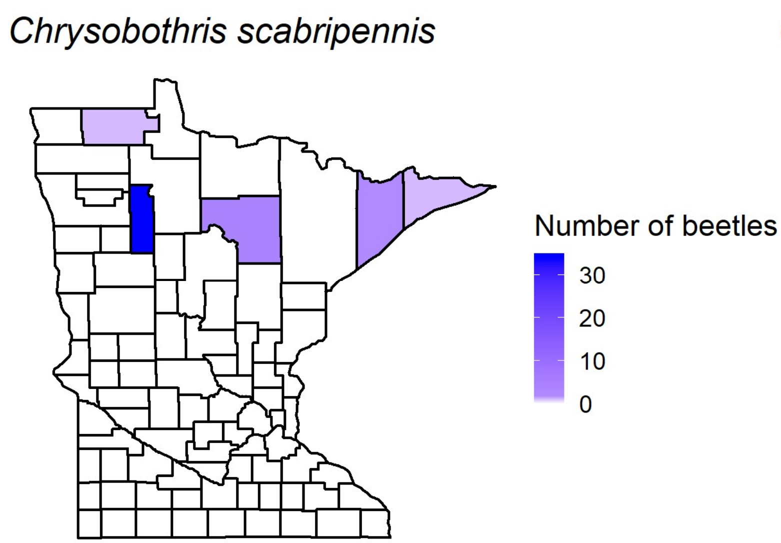

Chrysobothris quadriimpressa
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Chrysobothris rotundicollis
Number of beetles
3
2
1
0

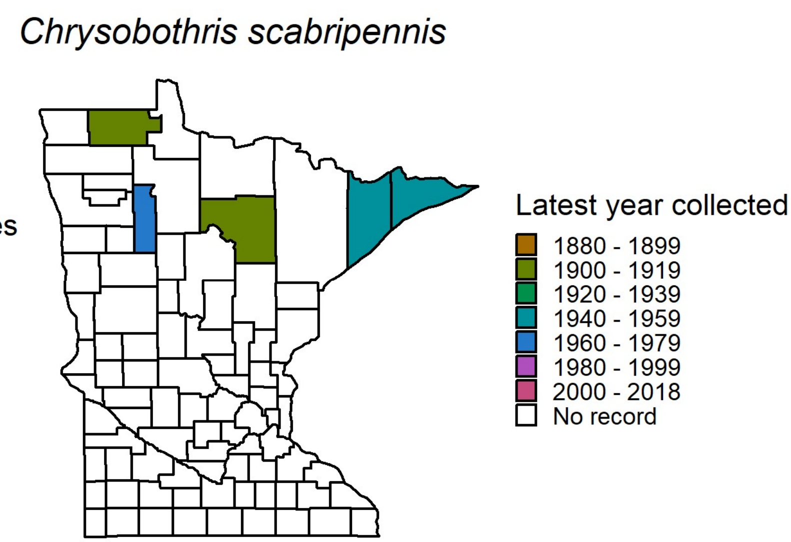

Chrysobothris rotundicollis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Chrysobothris rugosiceps
Number of beetles
3
2
1
0

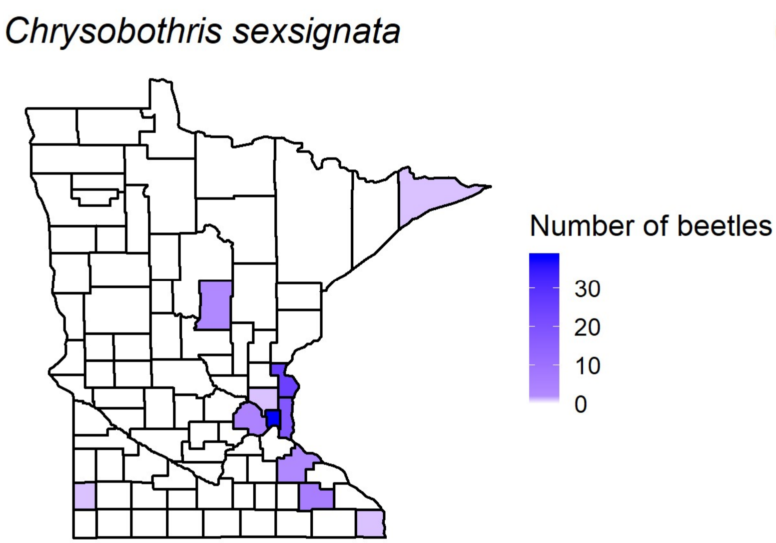

Chrysobothris rugosiceps
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

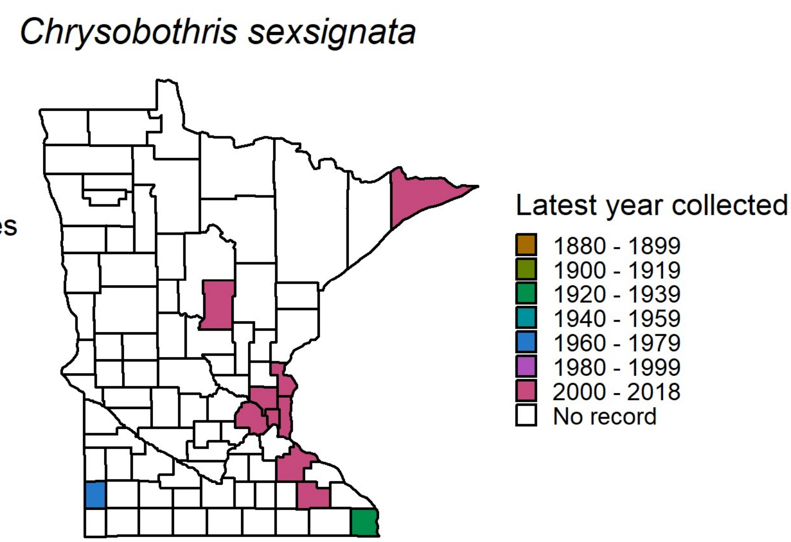


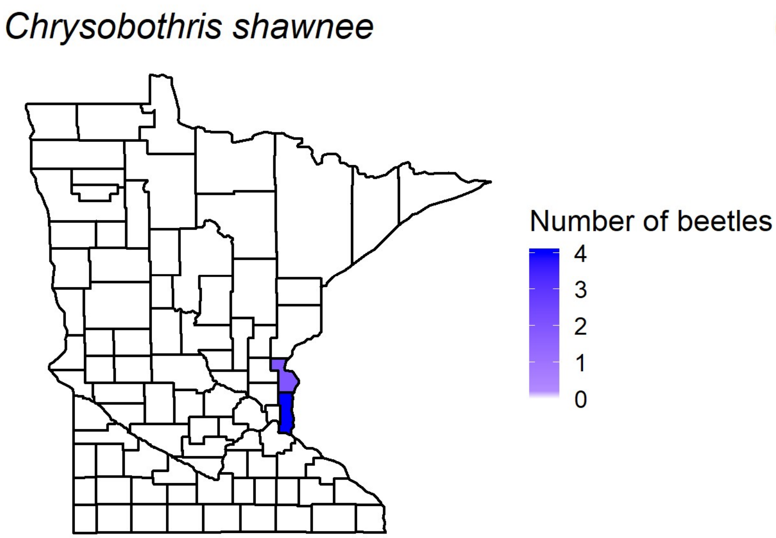
Chrysobothris scabripennis
Number of beetles
30
20
10
0

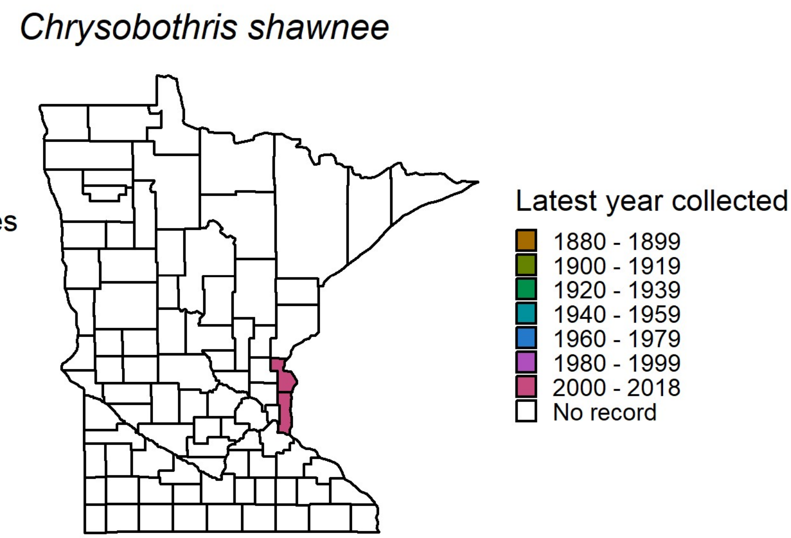


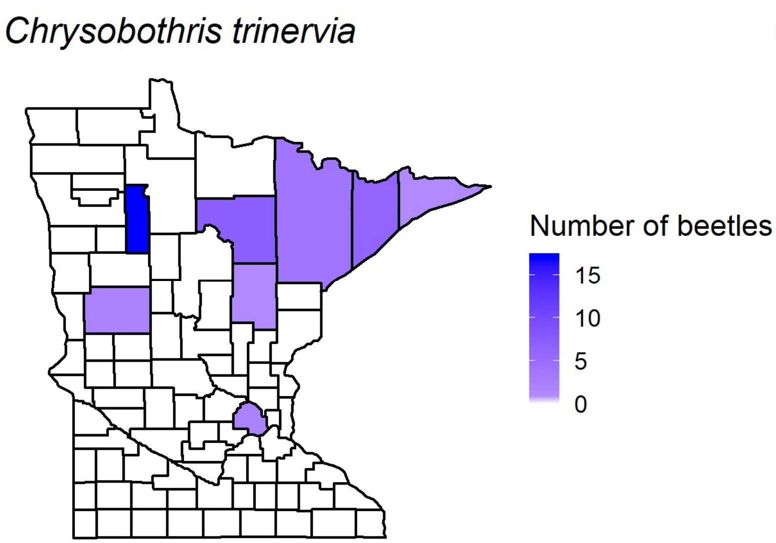
Chrysobothris scabripennis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

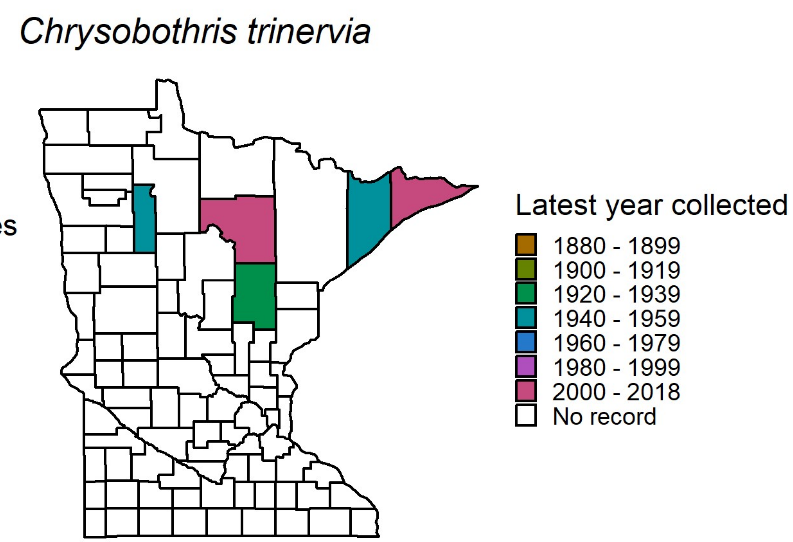

Chrysobothris sexsignata
Number of beetles
30
20
10
0


Chrysobothris sexsignata
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

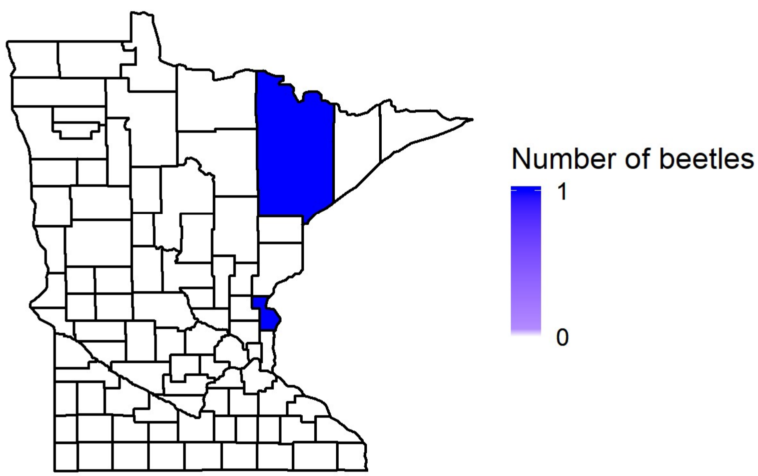

Chrysobothris shawnee
Number of beetles
4
3
2
1
0


Chrysobothris shawnee
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

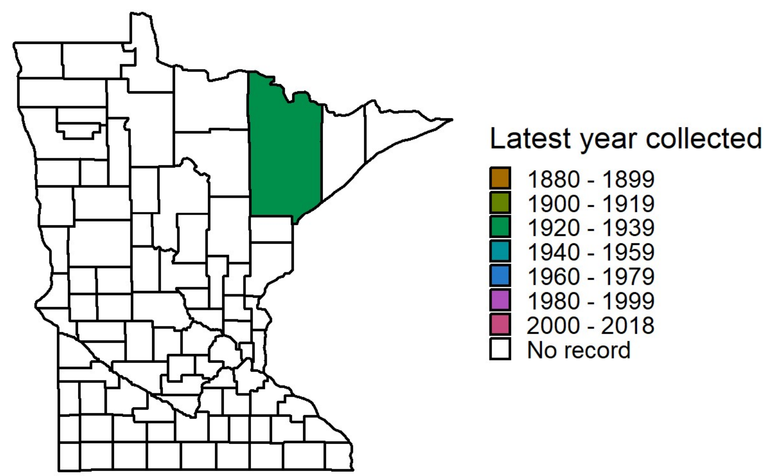

Chrysobothris trinervia
Number of beetles
15
10
5
0

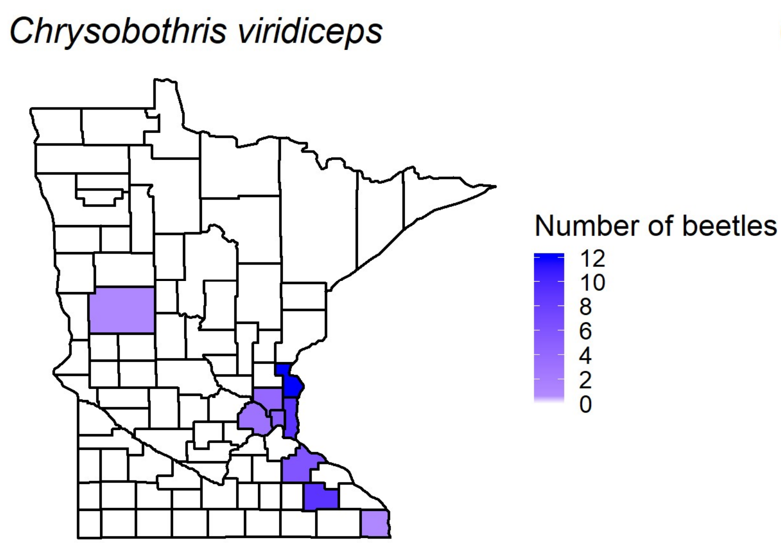

Chrysobothris trinervia
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

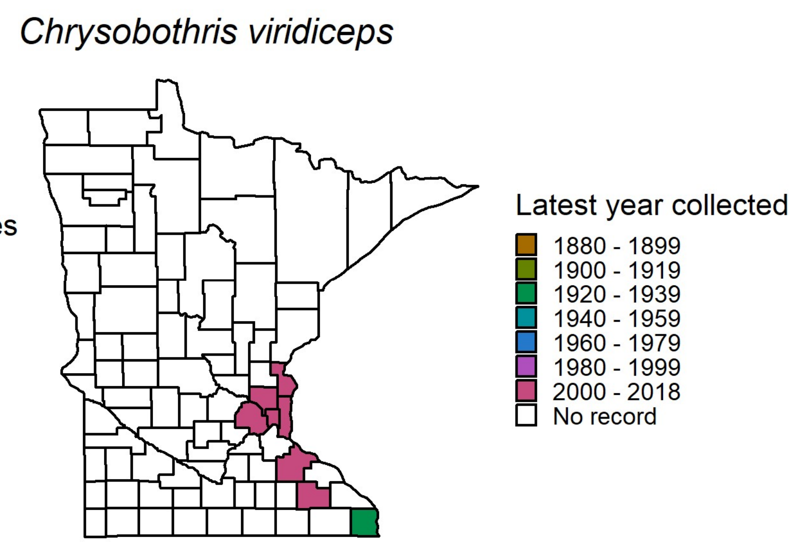
Chrysobothris verdigripennis

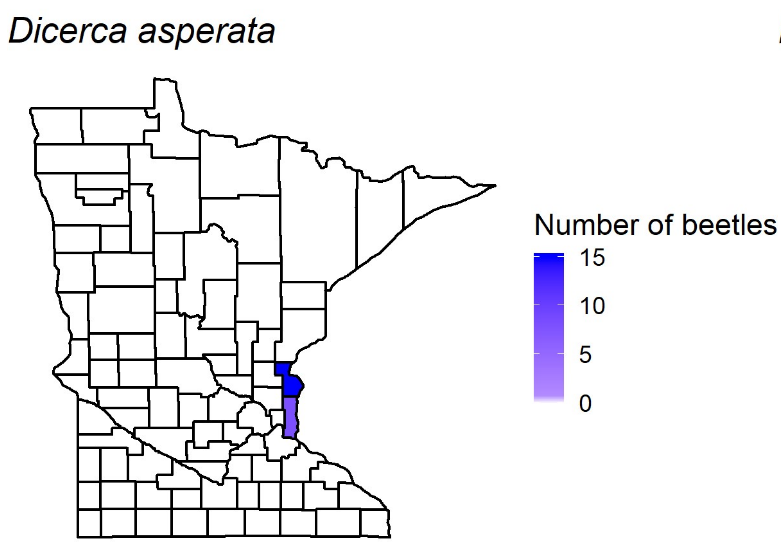


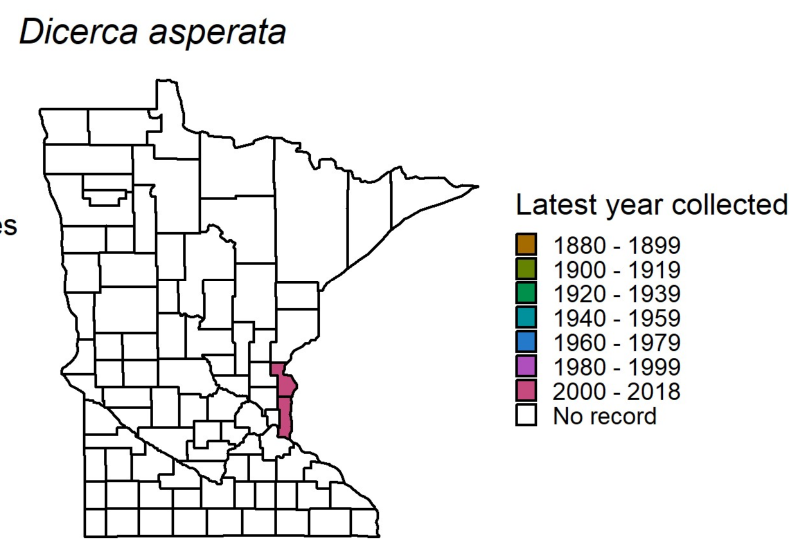
Chrysobothris verdigripennis

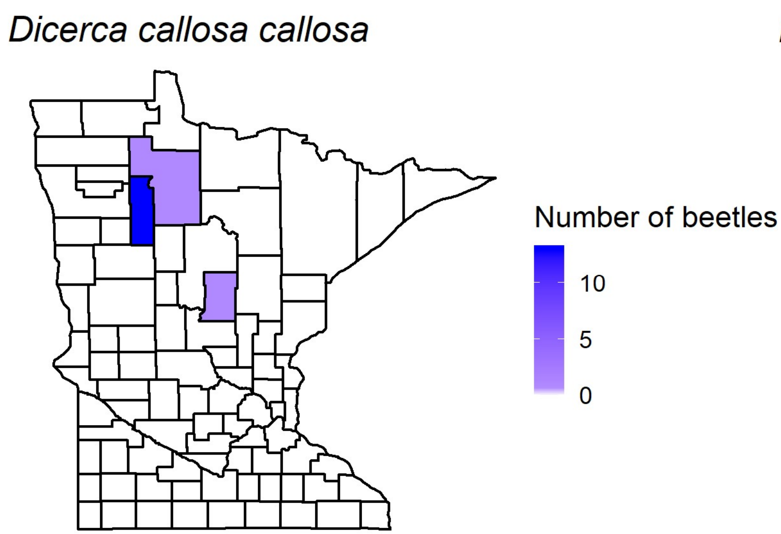


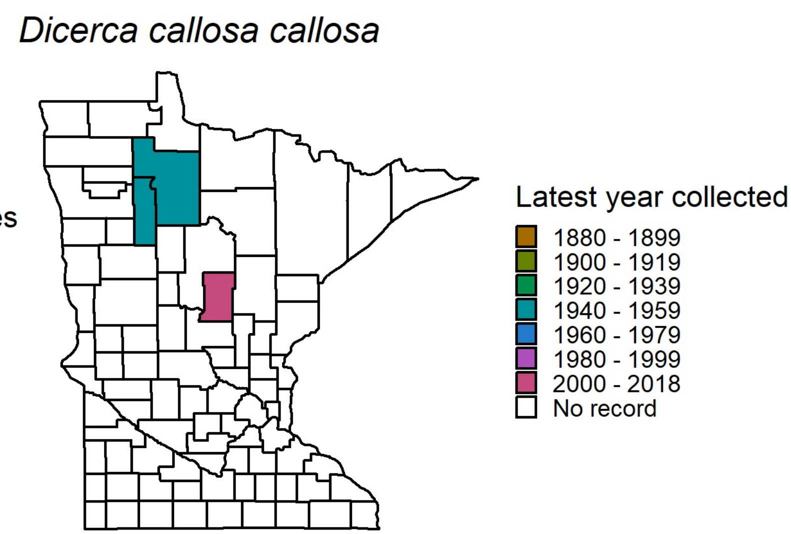

Chrysobothris viridiceps
Number of beetles
12
10
8
6
4
2
0

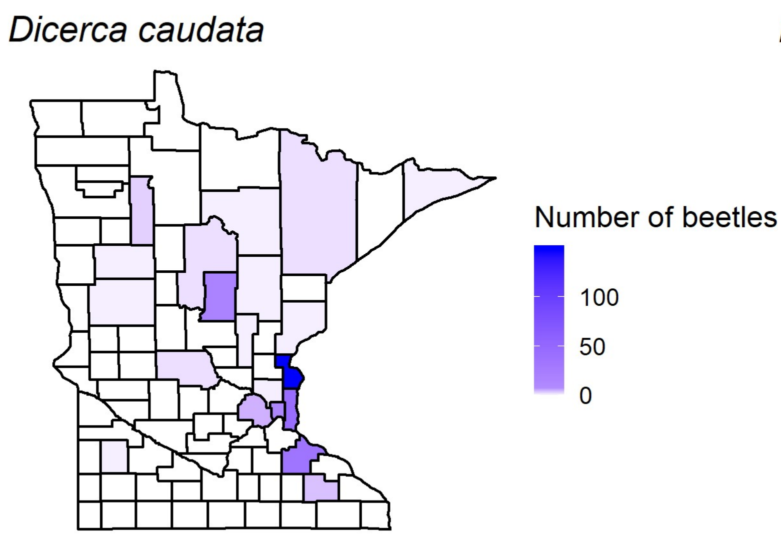

Chrysobothris viridiceps
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

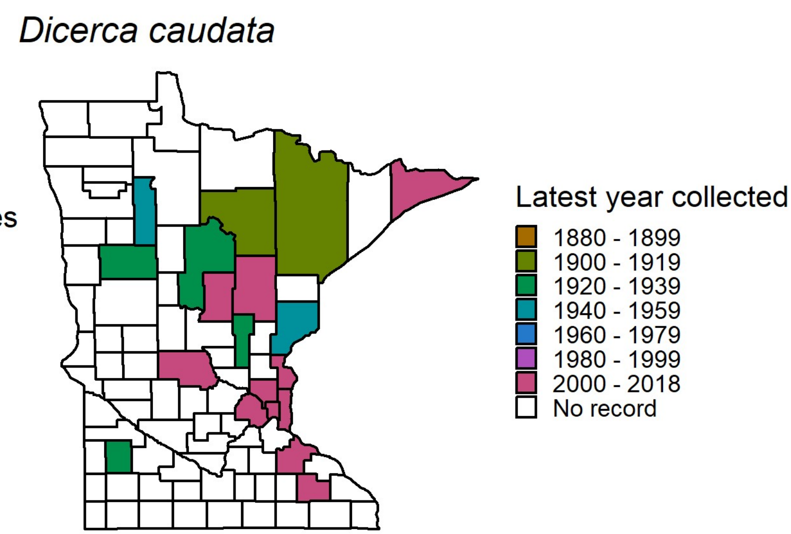

Dicerca asperata
Number of beetles
15
10
5
0

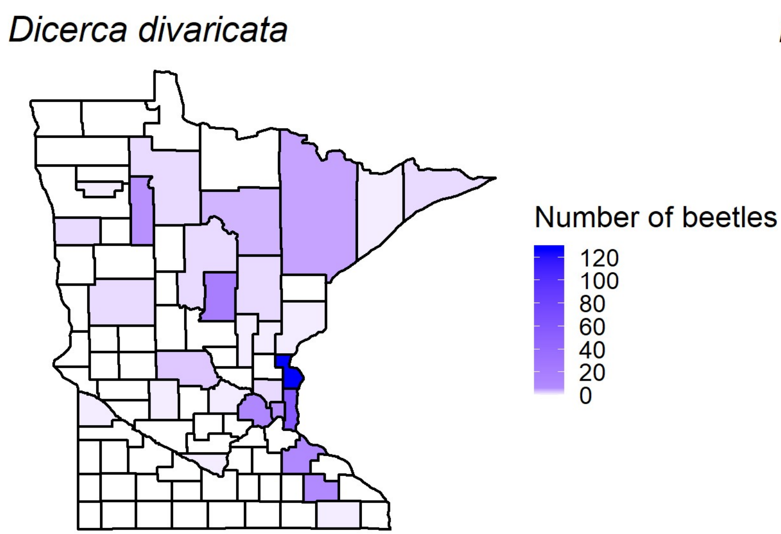

Dicerca asperata
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

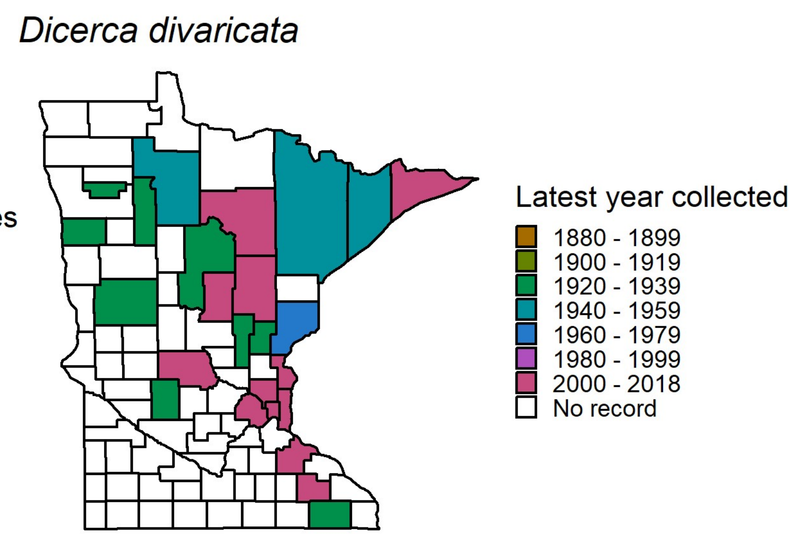

Dicerca callosa callosa
Number of beetles
10
5
0

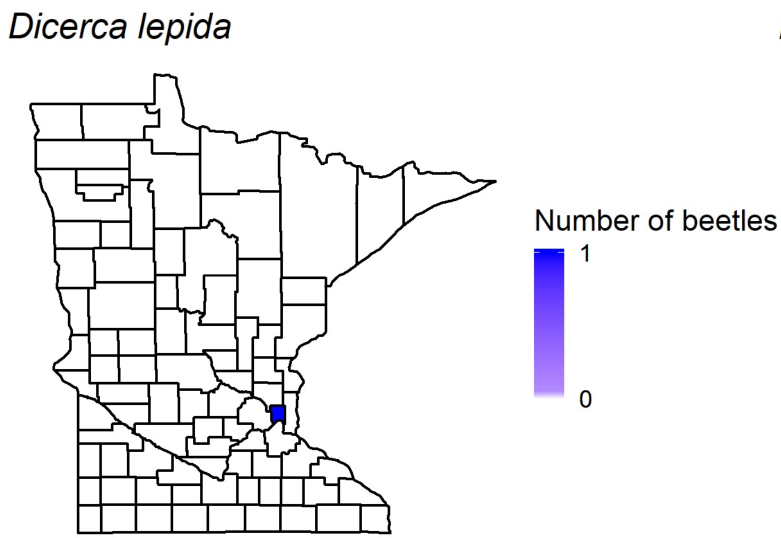

Dicerca callosa callosa
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Dicerca caudata
Number of beetles
100
50
0

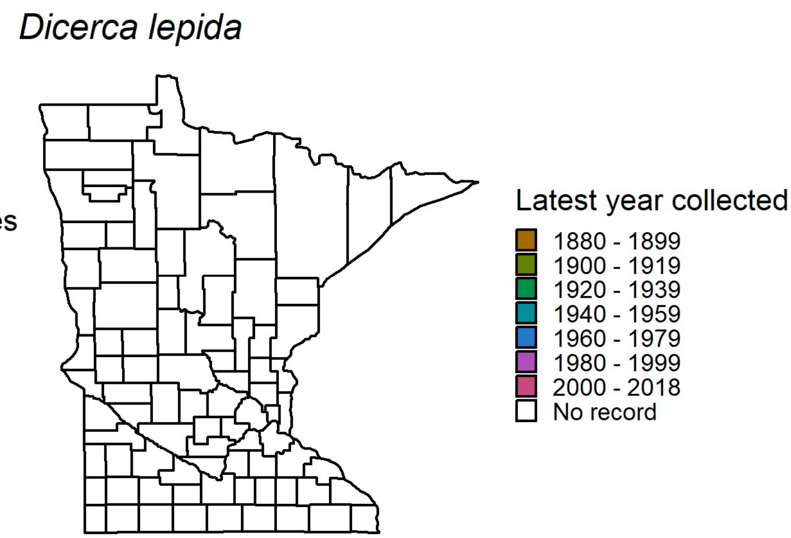

Dicerca caudata
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Dicerca divaricata
Number of beetles
120
100
80
60
40
20
0

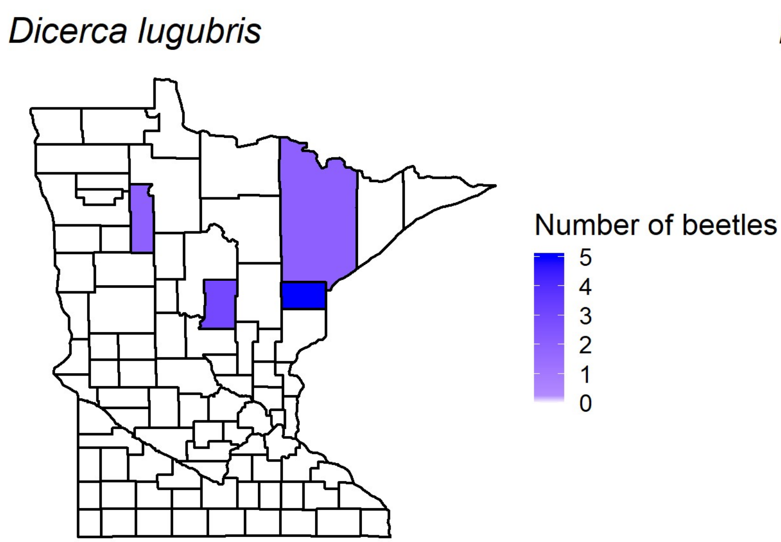

Dicerca divaricata
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

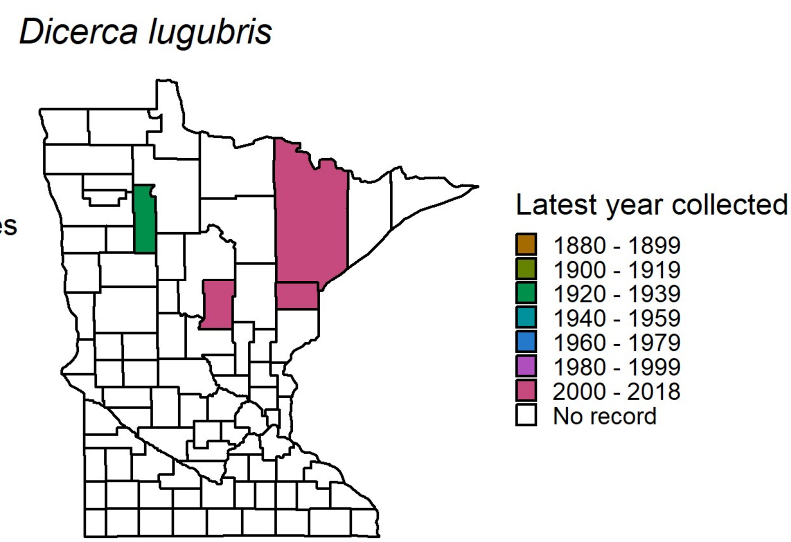


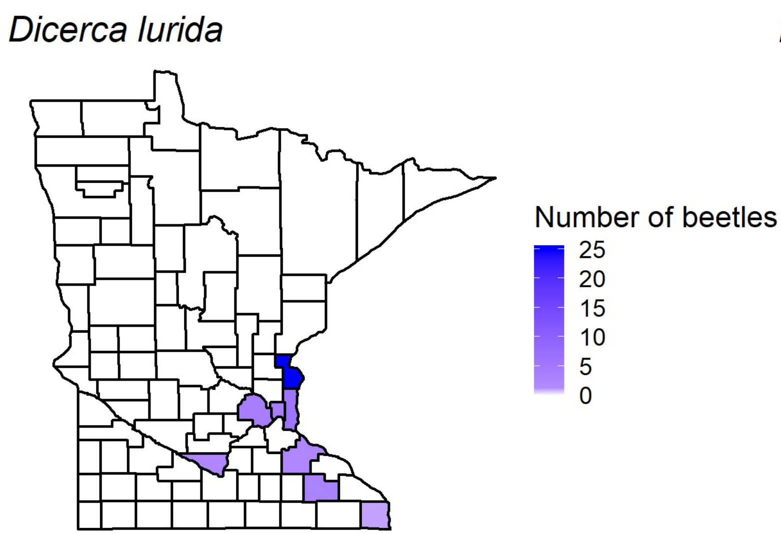
Dicerca lepida
Number of beetles
1
0

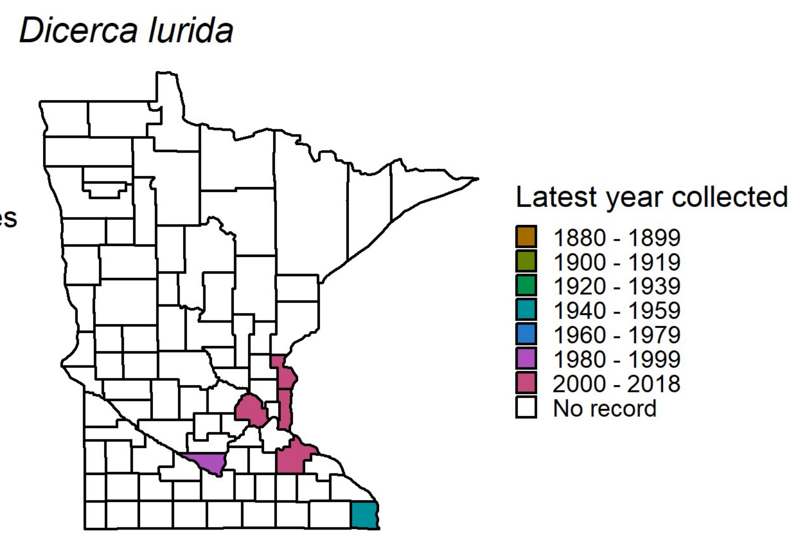


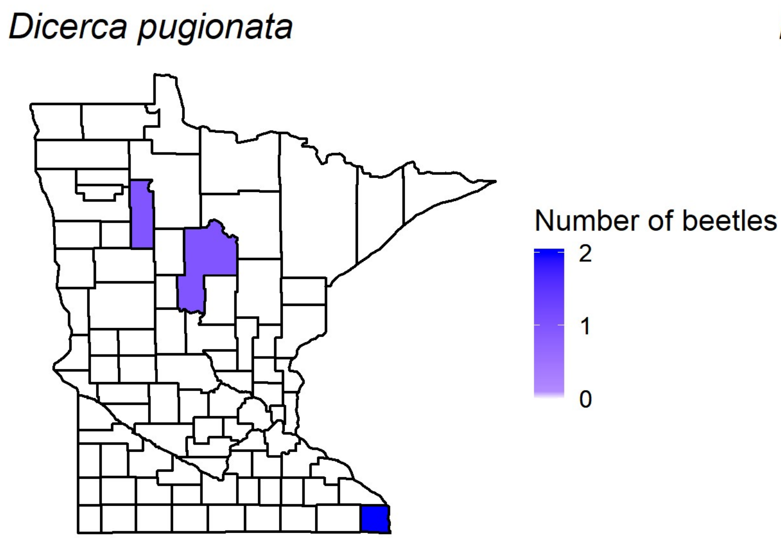
Dicerca lepida
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

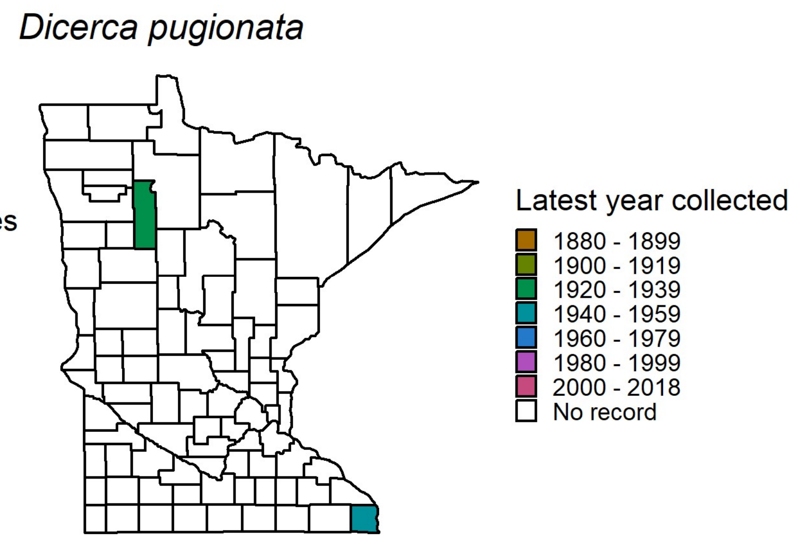

Dicerca lugubris
Number of beetles
5
4
3
2
1
0

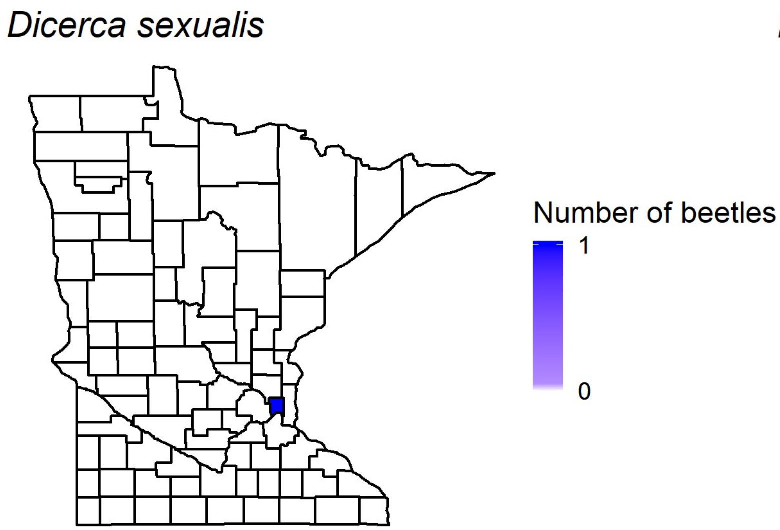

Dicerca lugubris
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

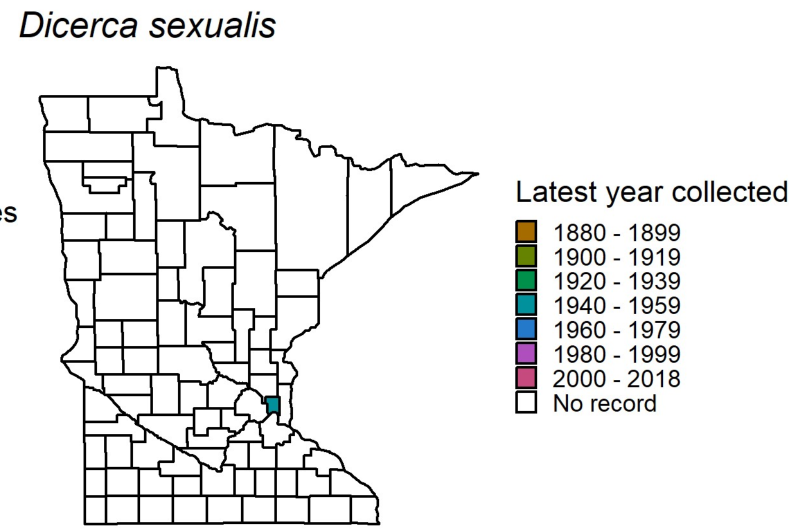

Dicerca lurida
Number of beetles
25
20
15
10
5
0

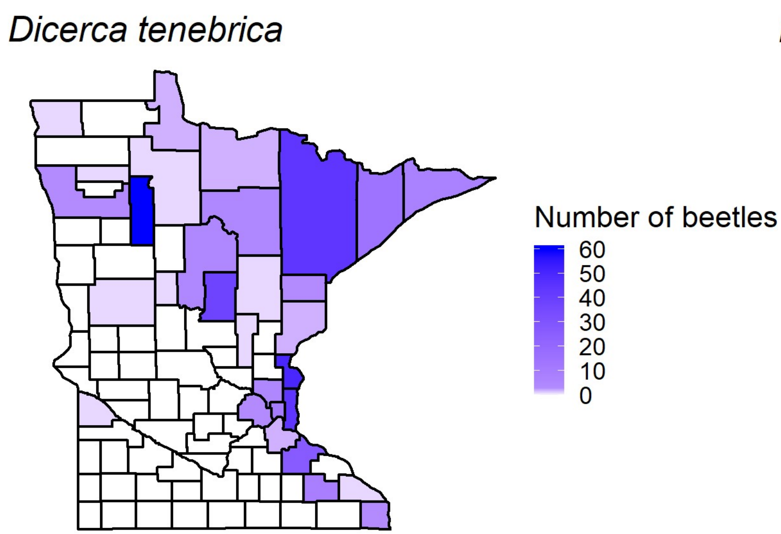

Dicerca lurida
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

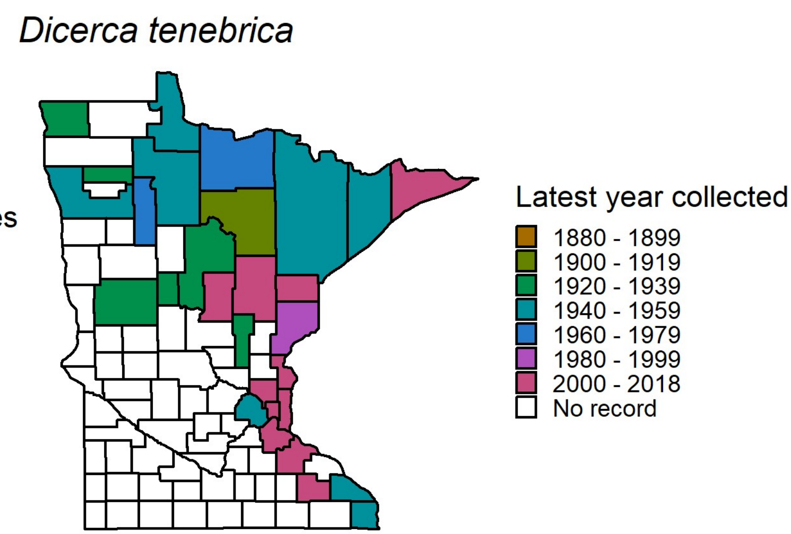

Dicerca pugionata
Number of beetles
2
1
0

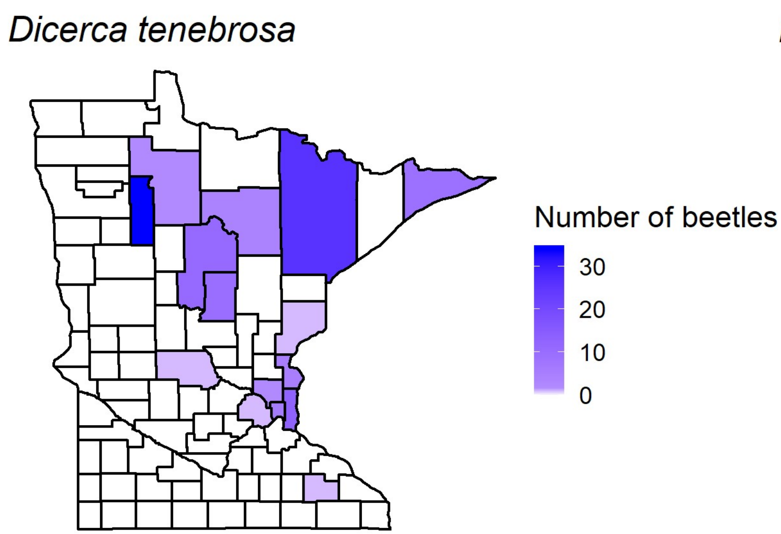

Dicerca pugionata
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

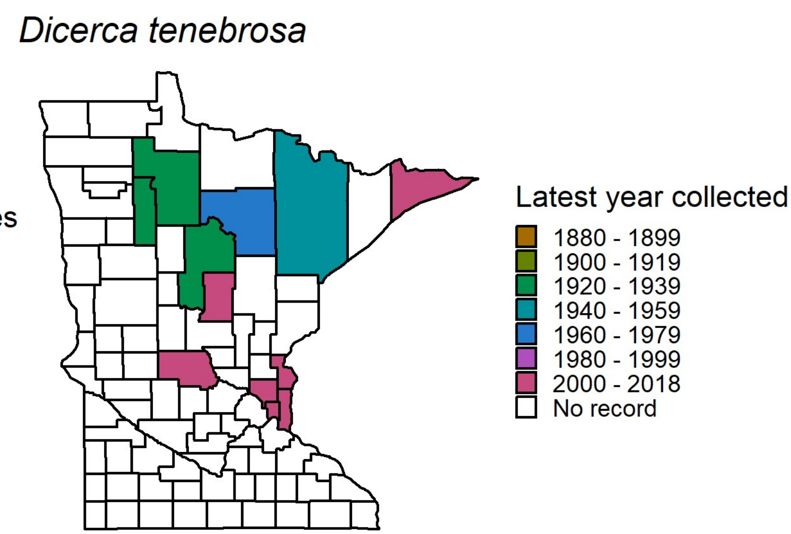

Dicerca sexualis
Number of beetles
1
0

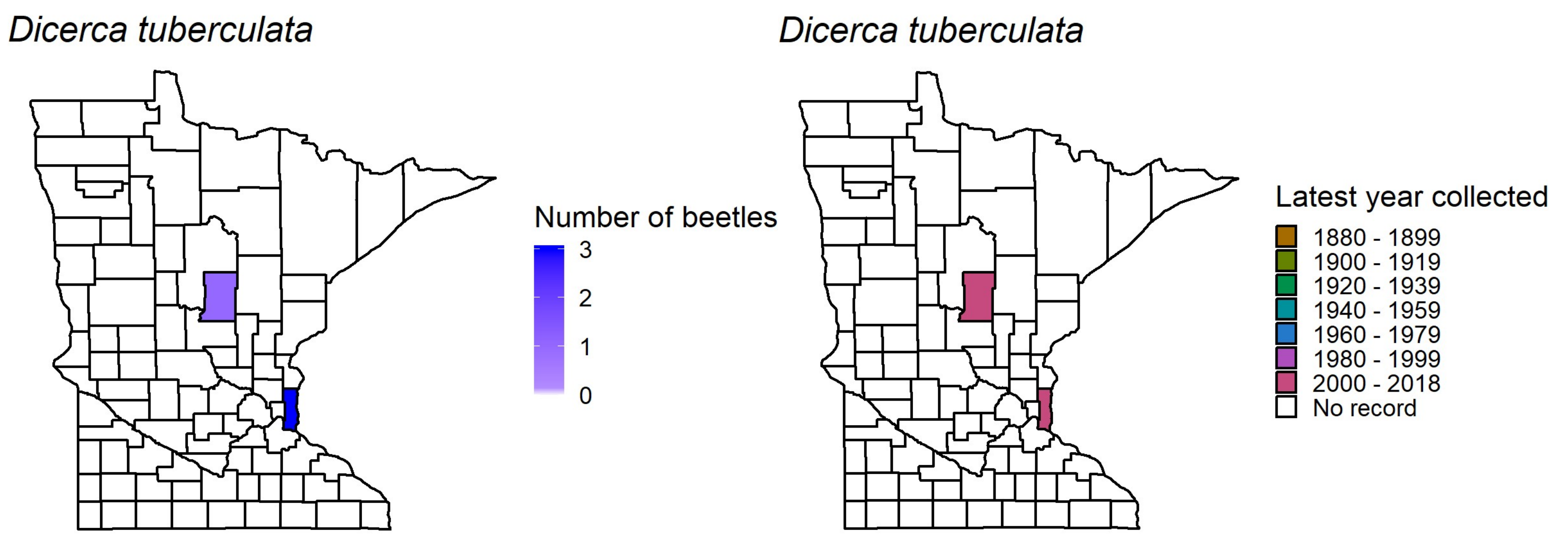

Dicerca sexualis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Dicerca tenebrica
Number of beetles
60
50
40
30
20
10
0

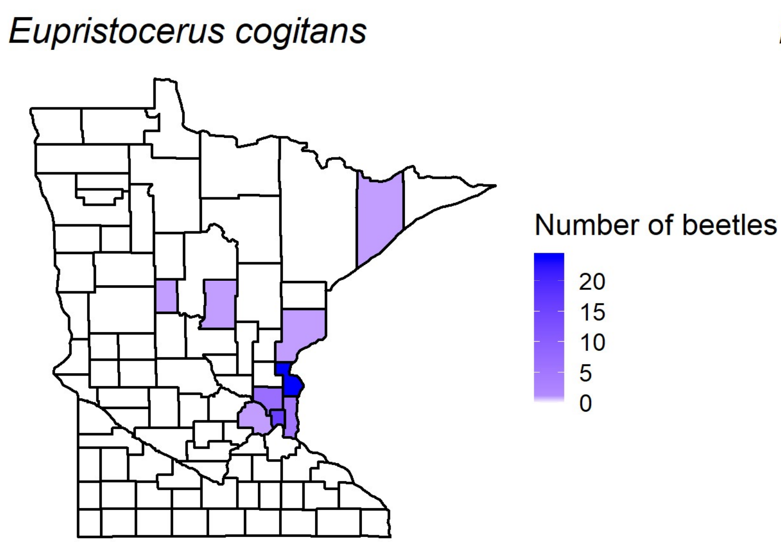

Dicerca tenebrica
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

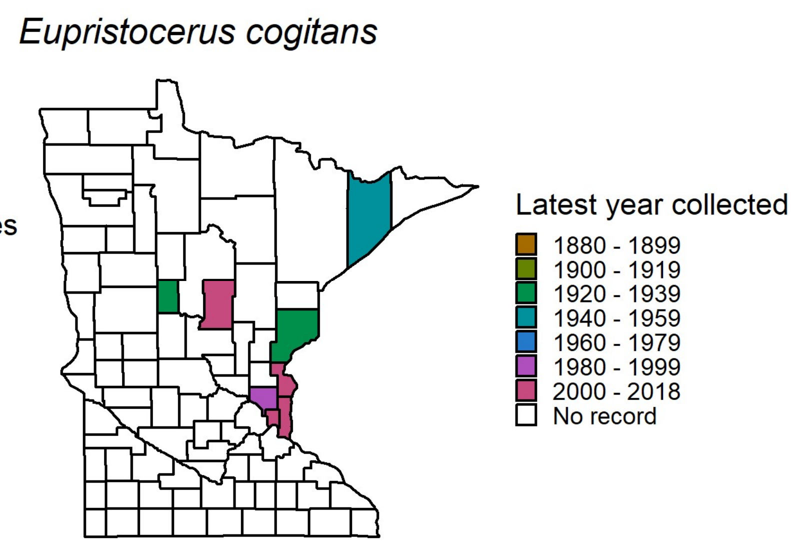

Dicerca tenebrosa
Number of beetles
30
20
10
0

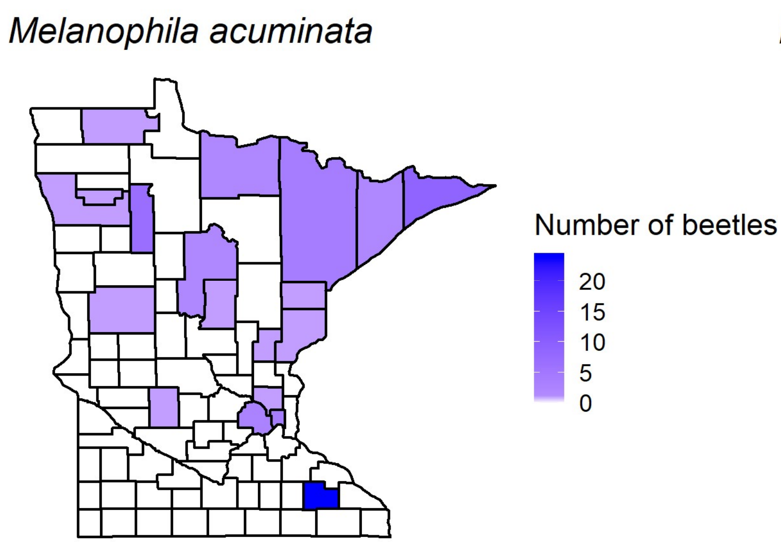

Dicerca tenebrosa
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

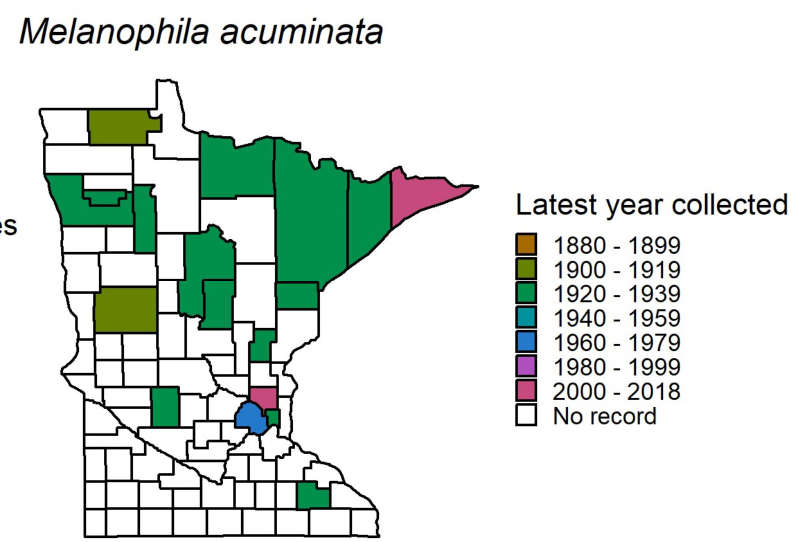


Dicerca tuberculata
Number of beetles
3
2
1
0
Dicerca tuberculata
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

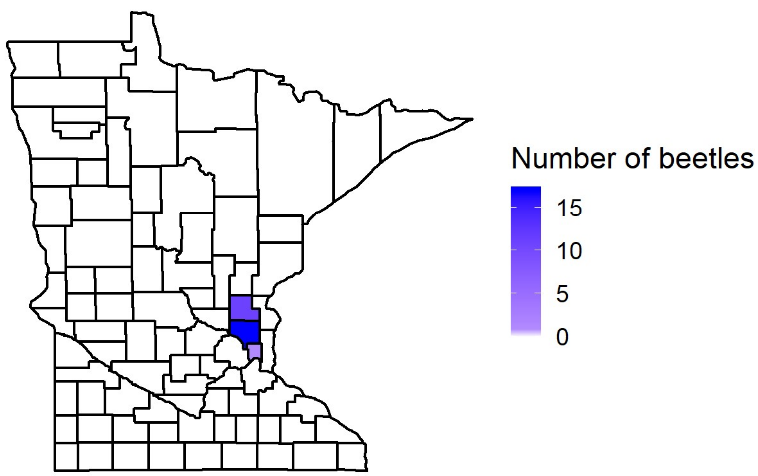

Eupristocerus cogitans
Number of beetles
20
15
10
5
0


Eupristocerus cogitans
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

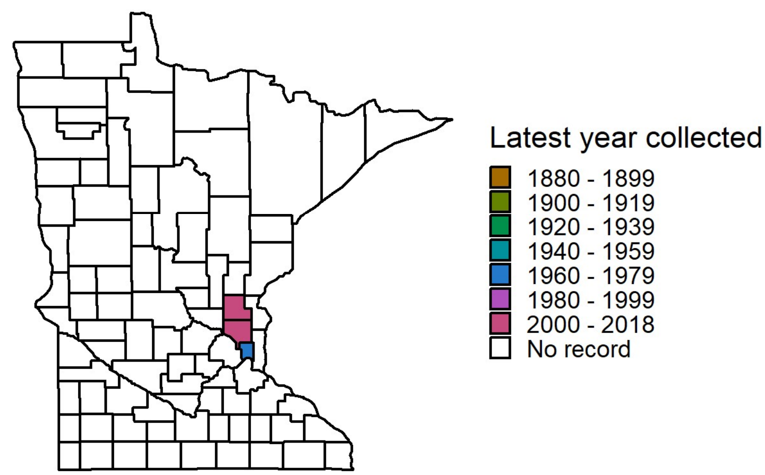

Melanophila acuminata
Number of beetles
20
15
10
5
0

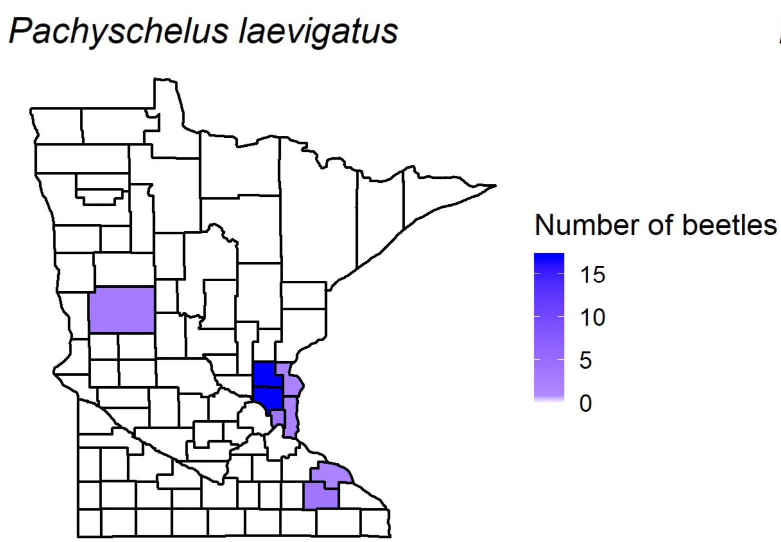

Melanophila acuminata
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

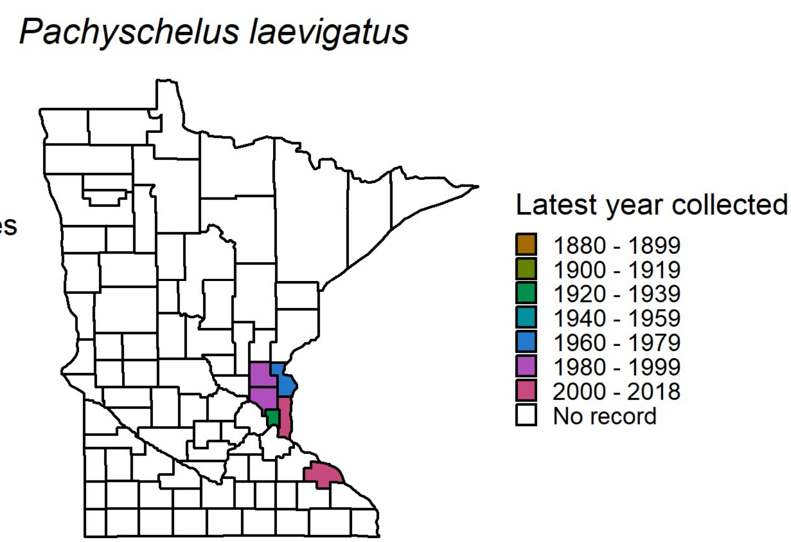
Pachyschelus confusus

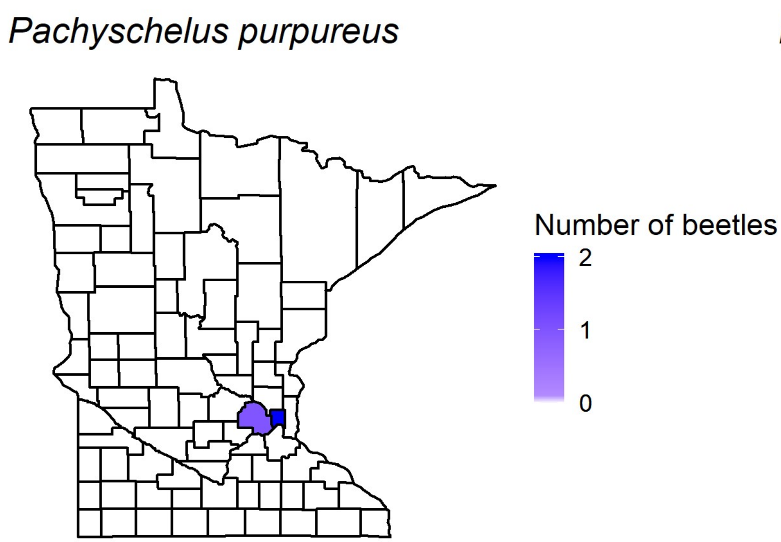


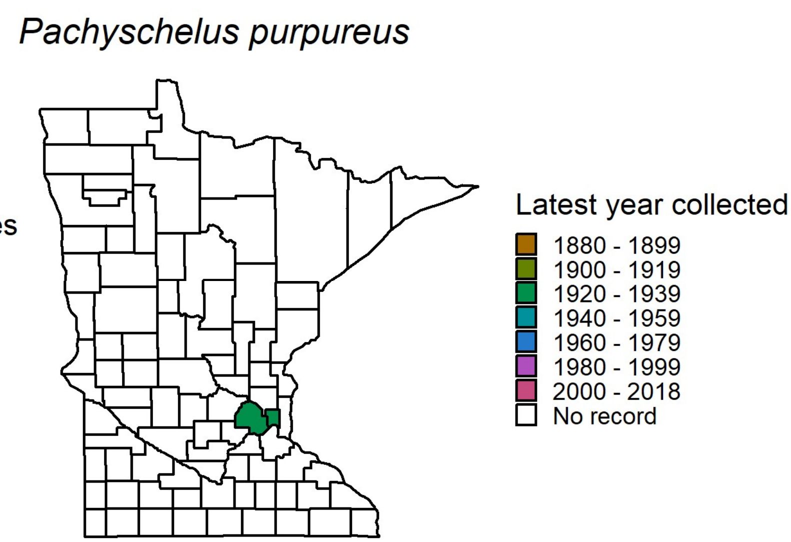
Pachyschelus confusus

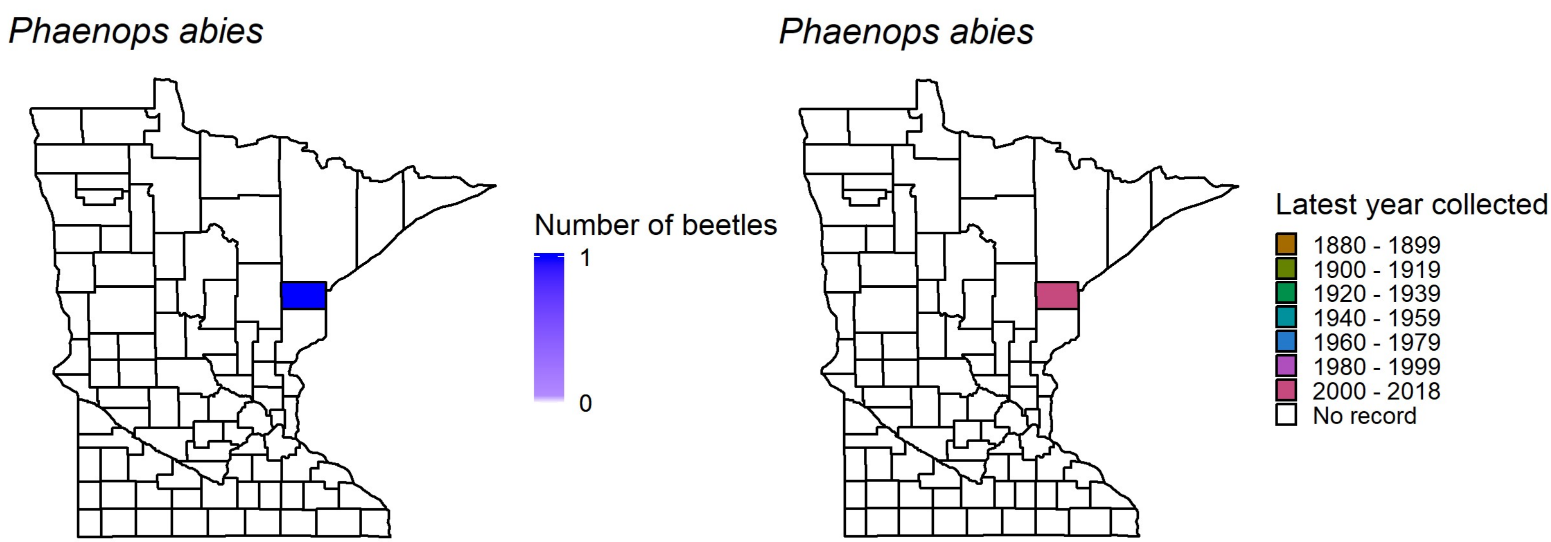


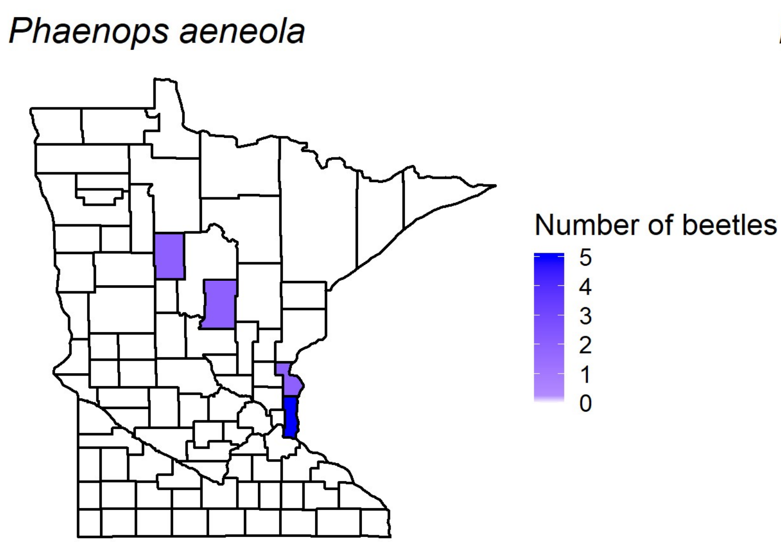

Pachyschelus laevigatus
Number of beetles
15
10
5
0


Pachyschelus laevigatus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

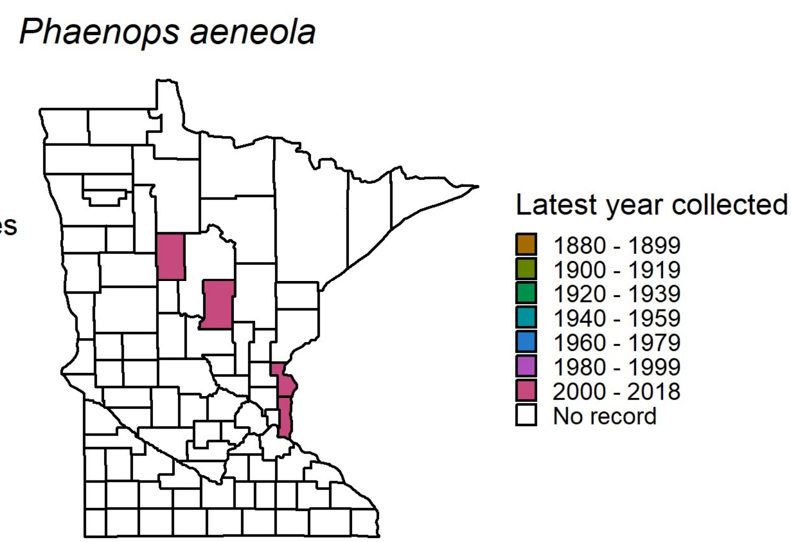

Pachyschelus purpureus
Number of beetles
2
1
0


Pachyschelus purpureus
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Phaenops abies
Number of beetles
1
0
Phaenops abies
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

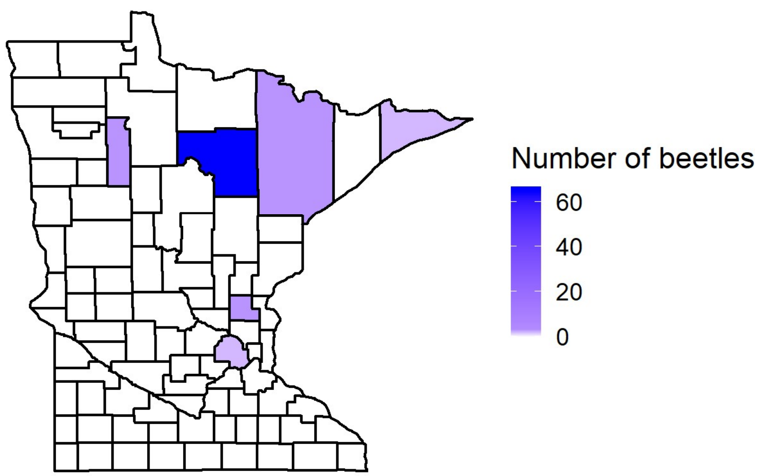


Phaenops aeneola
Number of beetles
5
4
3
2
1
0

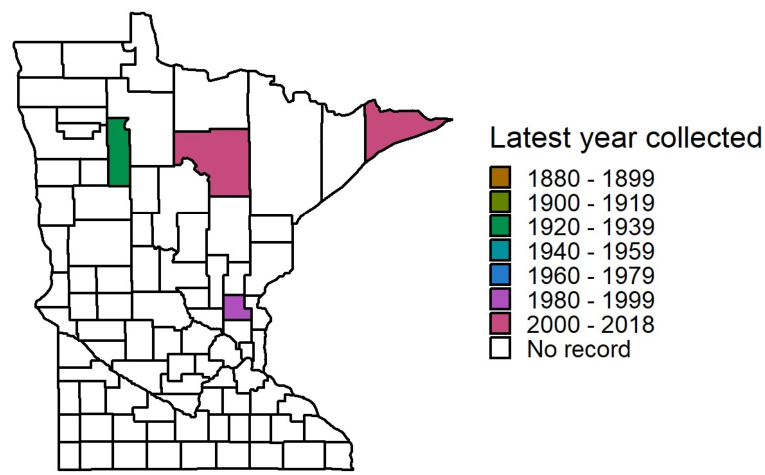


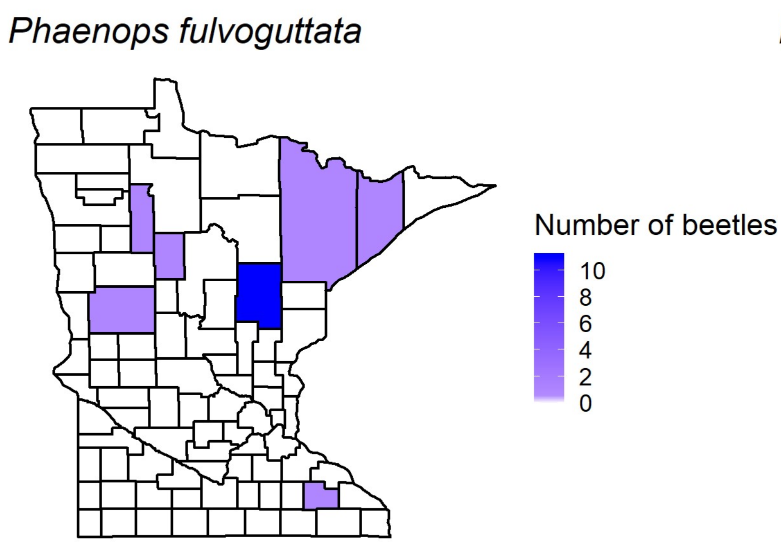
Phaenops aeneola
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

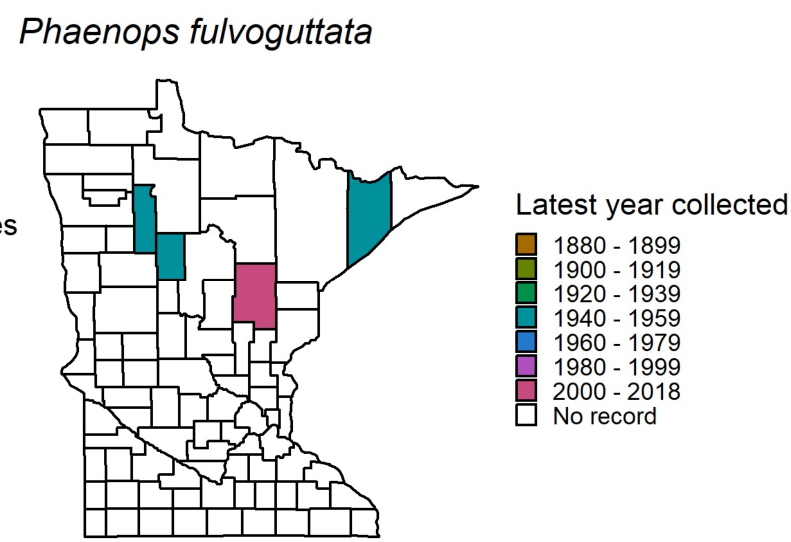
Phaenops drummondi

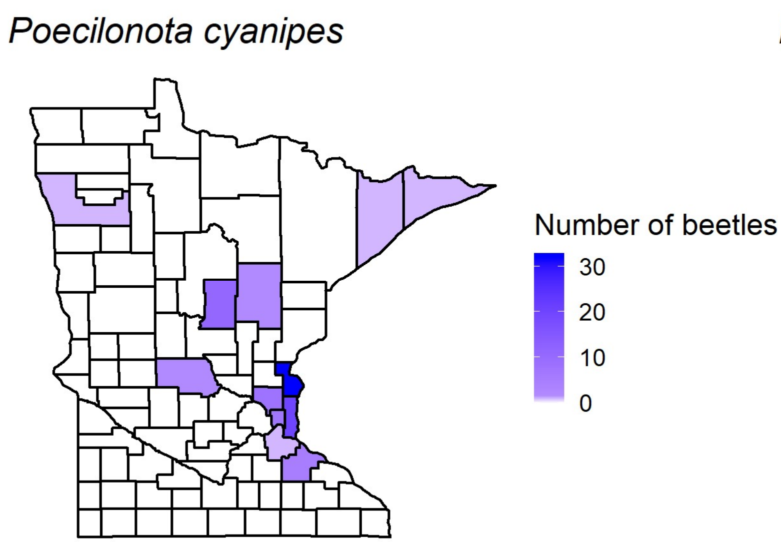


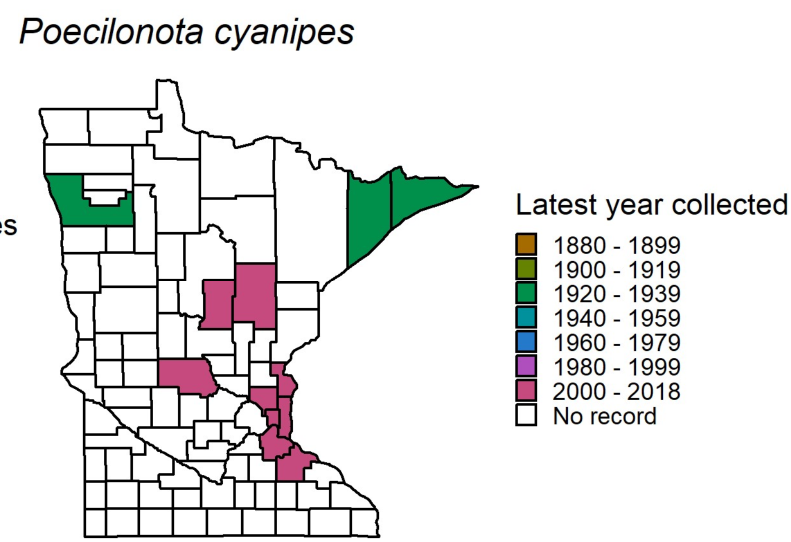
Phaenops drummondi

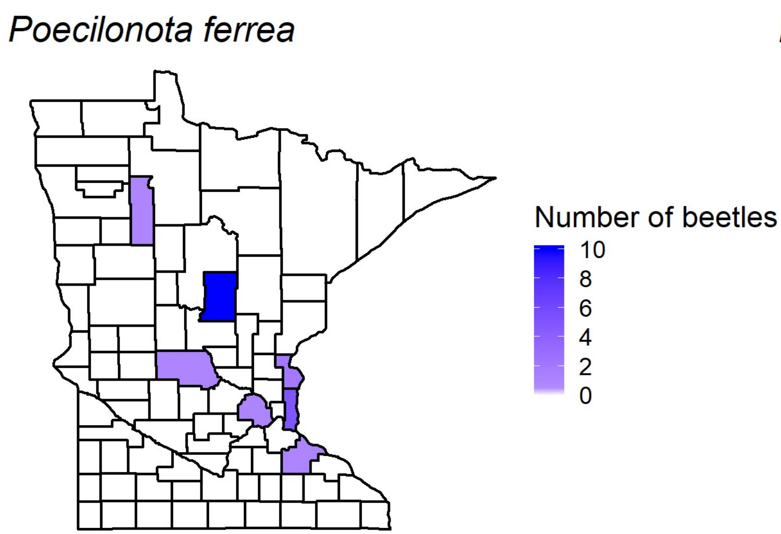



Phaenops fulvoguttata
Number of beetles
10
8
6
4
2
0

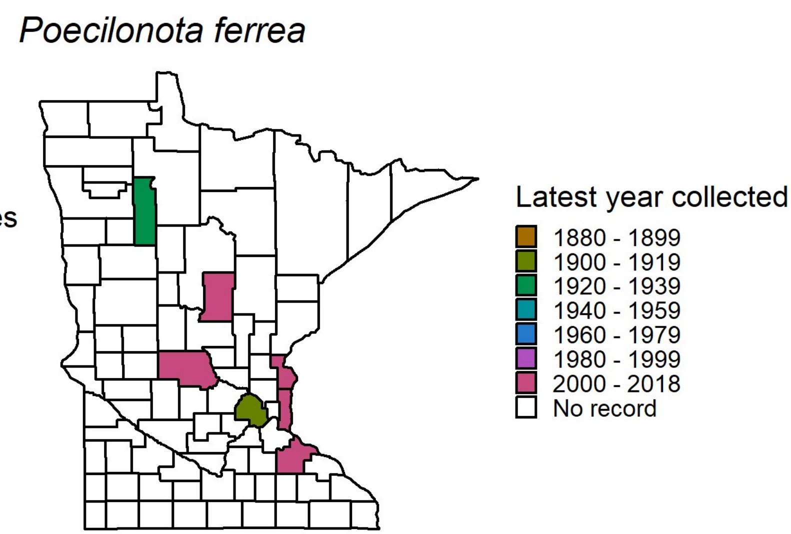

Phaenops fulvoguttata
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Poecilonota cyanipes
Number of beetles
30
20
10
0

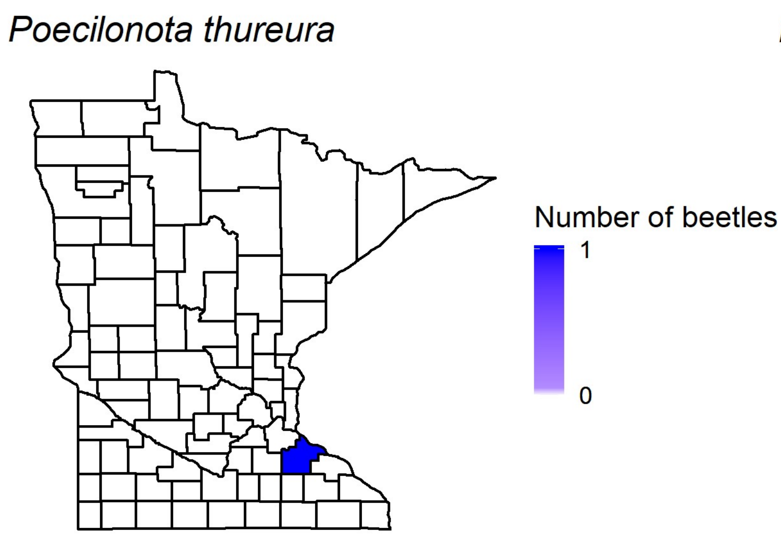

Poecilonota cyanipes
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

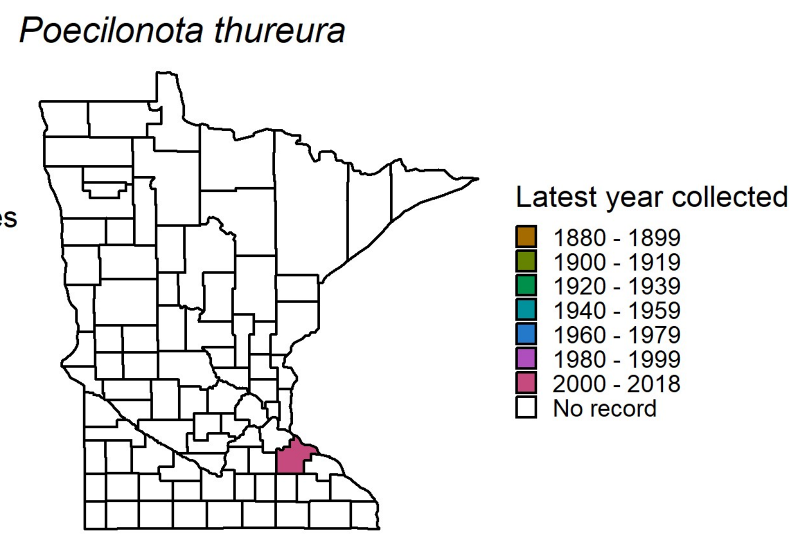


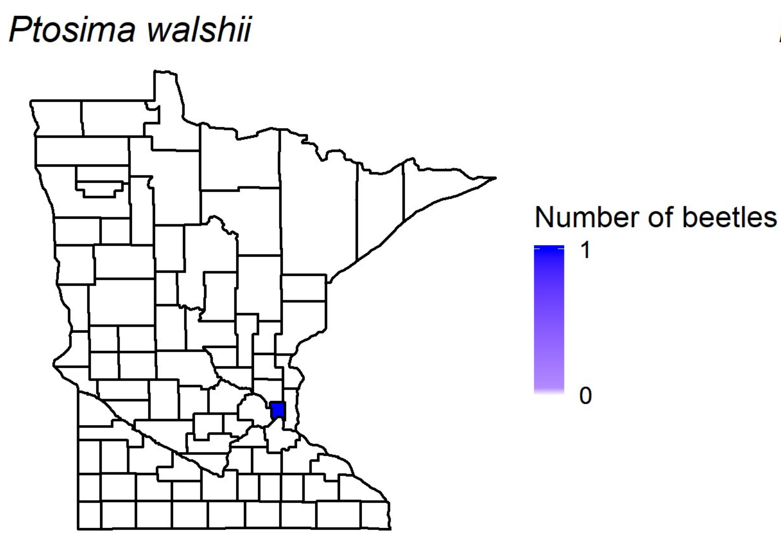
Poecilonota ferrea
Number of beetles
10
8
6
4
2
0



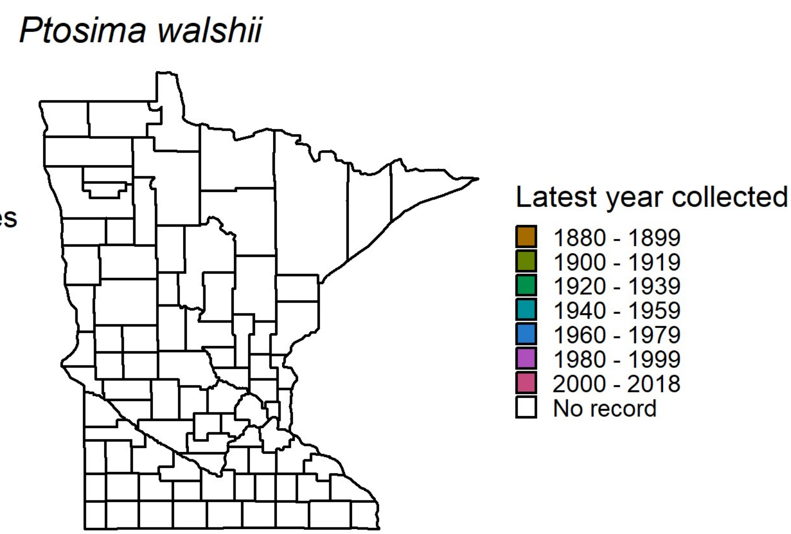
Poecilonota ferrea
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Poecilonota thureura
Number of beetles
1
0

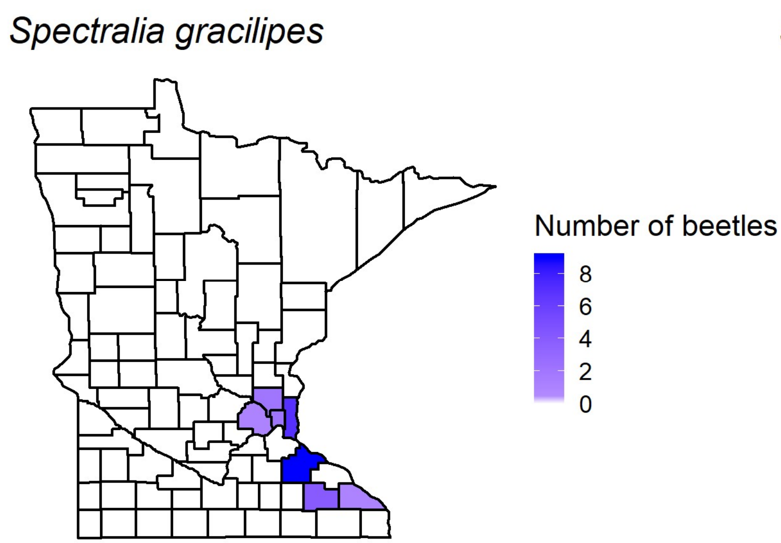

Poecilonota thureura
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

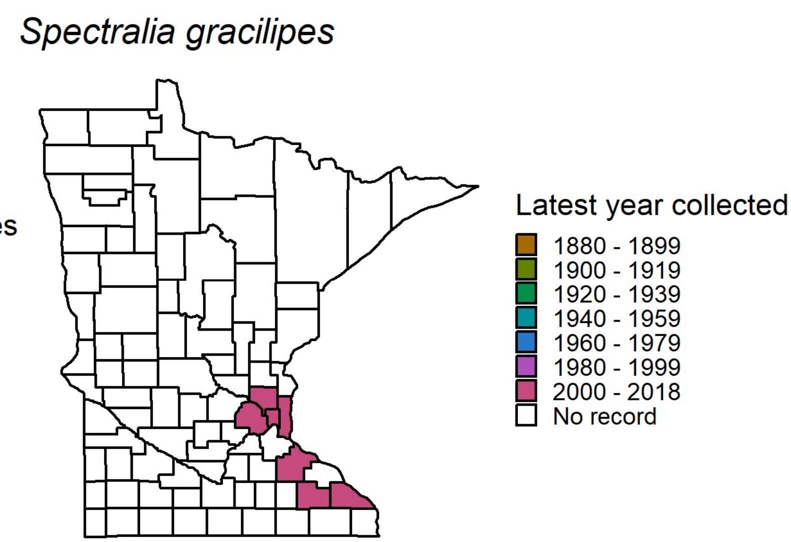


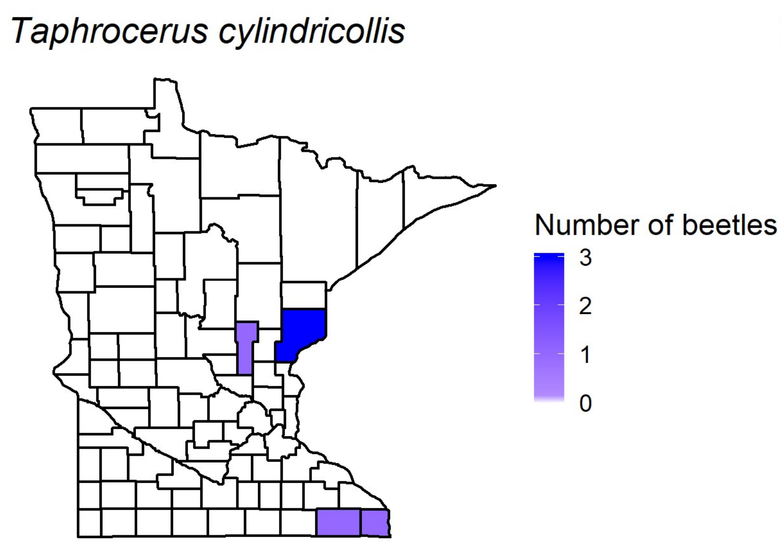
Ptosima walshii
Number of beetles
1
0

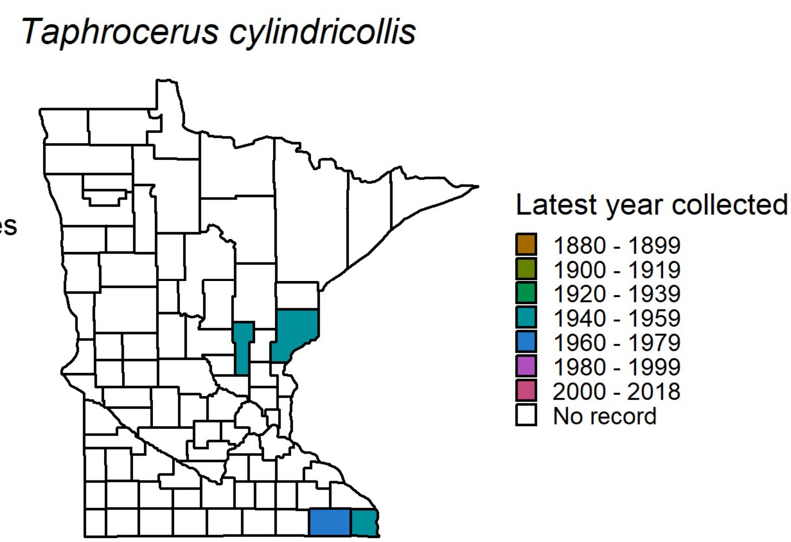


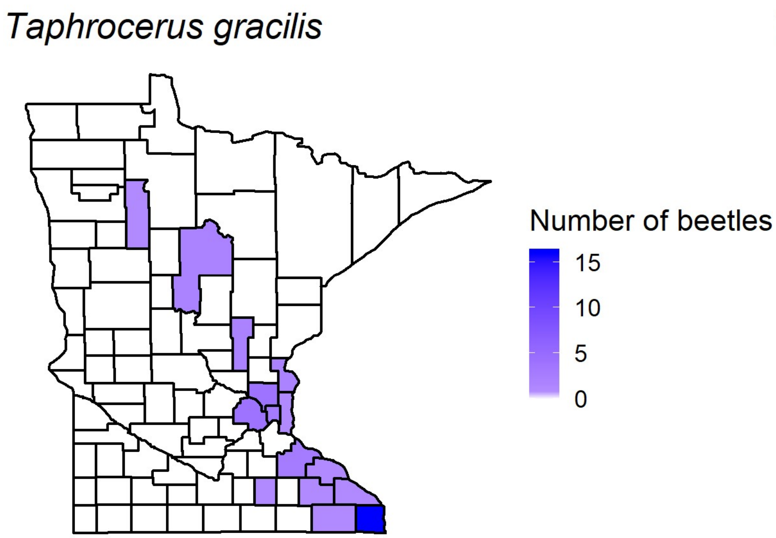
Ptosima walshii
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

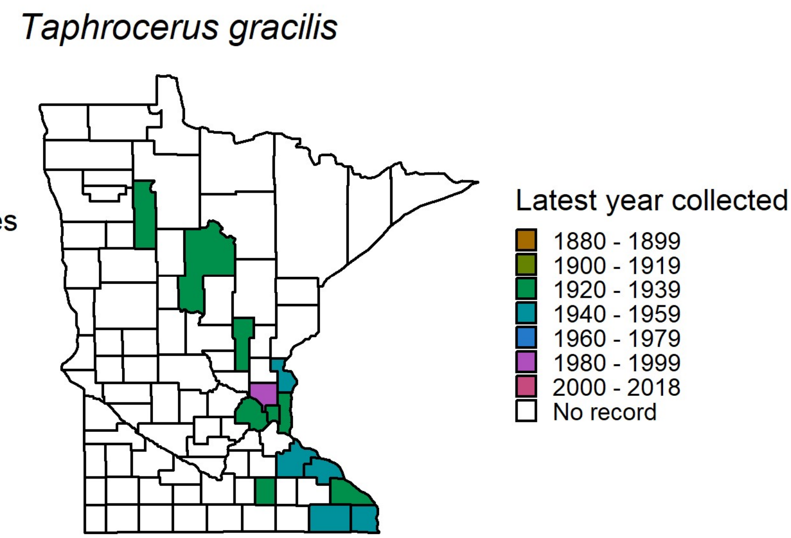

Spectralia gracilipes
Number of beetles
8
6
4
2
0

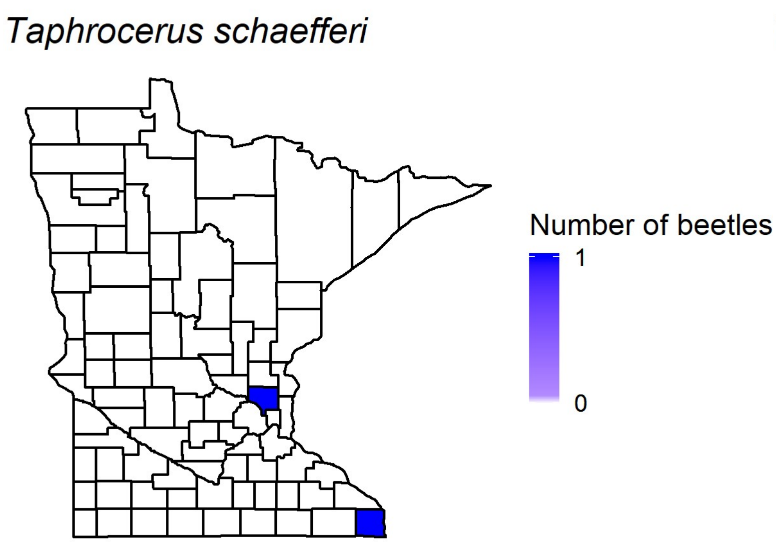

Spectralia gracilipes
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

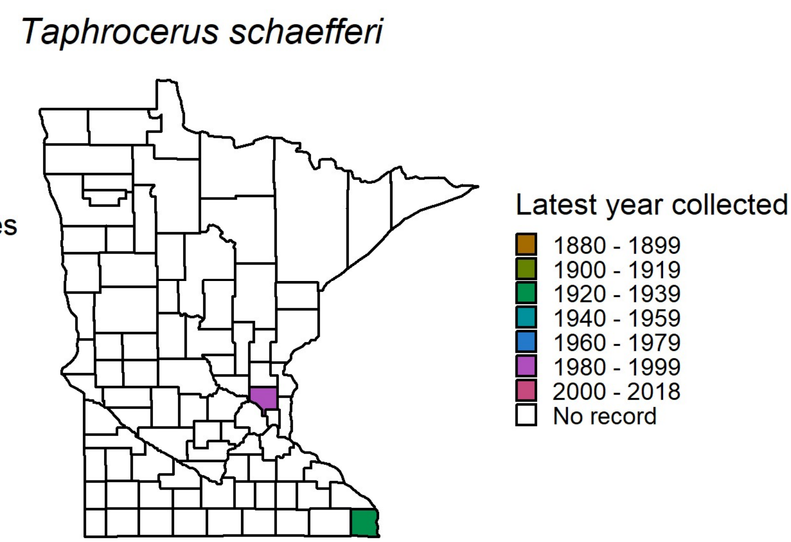

Taphrocerus cylindricollis
Number of beetles
3
2
1
0


Taphrocerus cylindricollis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Taphrocerus gracilis
Number of beetles
15
10
5
0

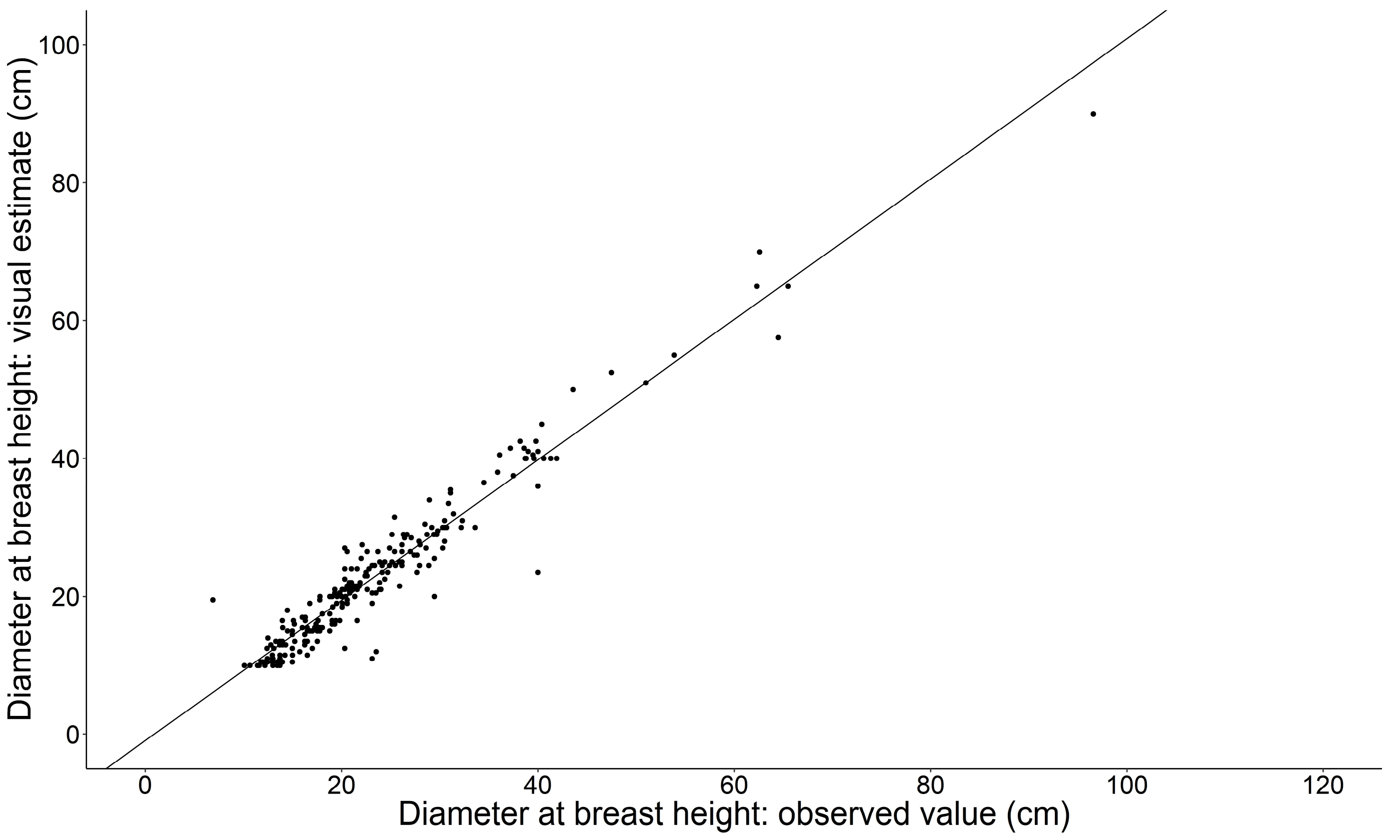

Taphrocerus gracilis
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record


Taphrocerus schaefferi
Number of beetles
1
0


Taphrocerus schaefferi
Latest year collected
1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
1980 - 1999
2000 - 2018
No record

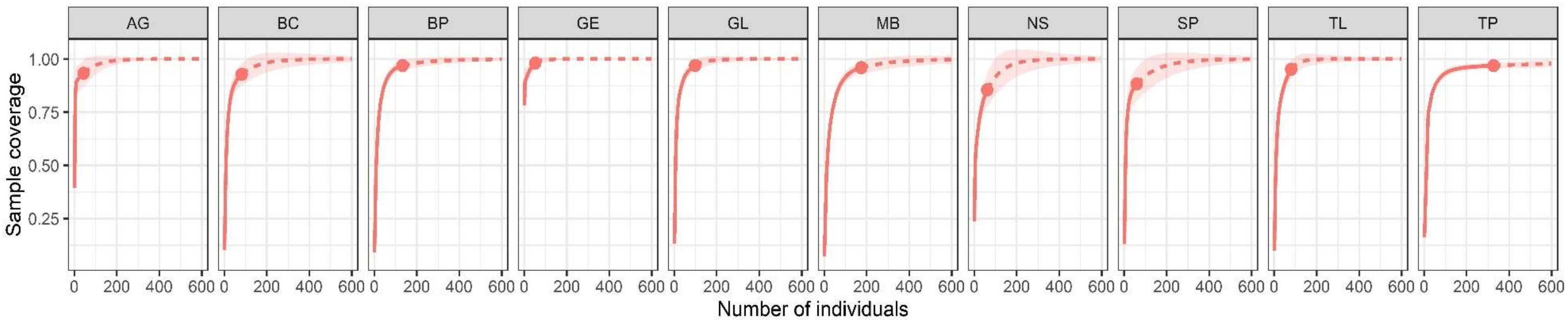
2.1 *Validating DBH visual estimates*

To validate our visual DBH estimates we created a linear regression of individual visual estimates against true DBH. Estimates from more than one person for a single tree were averaged ($N = 234$). The resulting slope was not significantly different from one, indicating no significant difference between our estimates and true DBH ($t = 0.983$, df = 232, $p = 0.32$).



2.2 *Sample coverage curves*

Number of individuals needed to reach different predicted sample coverages at the 10 *Cerceris fumipennis* nesting sites where we looked for relationships between buprestid species richness and site level characteristics. A sample coverage of 1.00 indicates 100% of species predicted to be present have been sampled. The solid line represents coverage based on the sample size collected, while the dotted line represents extrapolated coverage up to a sample size of 450 individuals. Red bands represent 95% confidence intervals.



3.1. *Wasp Watchers Survey Instrument*

Thank you for taking the time to complete the questionnaire! We look forward to your responses, which will improve the Wasp Watchers program and similar citizen science volunteer experiences moving forward. Please tell us about your experience with the Wasp Watchers program and your experience dealing with invasive species. As a reminder, citizen science programs are those that recruit members of the public to help gather or analyze scientific data.

Start by pressing the arrow to the right.

1. How many summers, if any, have you participated in the Wasp Watchers program?

○ I have not volunteered or attended a training session

○ 1 summer

○ 2 summers

○ 3 or more summers

2. Approximately how many hours of Wasp Watchers **training** have you attended?

○ Less than 1 hour

○ 1-2 hours

○ 3-4 hours

○ Over 4 hours

3. Approximately how many **total hours**, including training activities, have you spent volunteering for the Wasp Watchers?

○ Less than 1 hour

○ 1-4 hours

○ 5-10 hours

○ Over 10 hours

4. Did you participate in the most recent summer of Wasp Watching activities (2018)?

- Yes
- No

5. How knowledgeable, if at all, are you on the following topics?

	Not at all knowledgeable	Slightly knowledgeable	Moderately knowledgeable	Very knowledgeable
The smokey winged beetle bandit wasp (*Cerceris fumipennis*)	○	○	○	○
Emerald ash borer lifecycle	○	○	○	○
Emerald ash borer management	○	○	○	○
Invasive insects in general	○	○	○	○
Invasive plants in general	○	○	○	○

6. Not including Wasp Watchers training sessions, how many times during the past six months have you sought out information about emerald ash borer, if at all?

- Not at all (1)
- Once (2)
- 2-3 times (3)
- 4-5 times (4)
- More than 5 times (5)

7. Since your participation in the Wasp Watchers program, how has your interest changed, if at all, in the following activities?

	Much less interested	Slightly less interested	Same level of interest	Slightly more interested	Much more interested
Reading about **emerald ash borer**	○	○	○	○	○
Reading about **other invasive insects**	○	○	○	○	○
Reading about **invasive plants**	○	○	○	○	○
Reading about **environmental issues**	○	○	○	○	○
Attending an informational meeting about **emerald ash borer**	○	○	○	○	○
Attending an informational meeting about **other invasive insects**	○	○	○	○	○
Attending an informational meeting about **invasive plants**	○	○	○	○	○
Volunteering for **other citizen science projects**	○	○	○	○	○

8. Have you ever brought a family member or friend to a Wasp Watchers training?

- Yes
- No
- Not applicable

9. Have you ever brought a family member or friend to a non-training Wasp Watchers activity (searching for *Cerceris* nesting sites or beetle collecting)?

- Yes
- No
- Not applicable

10. How many times, if at all, have you taken the following actions?

	Not at all	Once	2-3 times	More than 3 times	Not applicable
Spoken with **family members** about the Wasp Watchers program	○	○	○	○	○
Spoken with **friends** about the Wasp Watchers program	○	○	○	○	○
Posted about the Wasp Watchers program on **social media**	○	○	○	○	○

11. Since participating in the Wasp Watchers program, how has your likelihood changed, if at all, of taking part in the following activities?

	Much less likely	Somewhat less likely	About the same likelihood	Somewhat more likely	Much more likely	Not applicable
Speaking with a **family member** about emerald ash borer	○	○	○	○	○	○
Speaking with a **friend** about emerald ash borer	○	○	○	○	○	○
Speaking with a **community group** about emerald ash borer	○	○	○	○	○	○
Speaking with your **neighborhood association** about emerald ash borer	○	○	○	○	○	○
Speaking with a **representative from your community** about its emerald ash borer management plan	○	○	○	○	○	○
Posting information about emerald ash borer on **social media**	○	○	○	○	○	○
Inviting a **family member** to volunteer for a citizen science program	○	○	○	○	○	○
Inviting a **friend** to volunteer for a citizen science program	○	○	○	○	○	○

12. To what extent do you agree or disagree with the following statements?

	Disagree	Slightly disagree	Slightly agree	Agree	Not applicable
I feel confident in my ability to manage **emerald ash borer** on my **property**					
I am able to influence management of **other invasive insects** on my **property**					
I am capable of controlling **invasive plants** on my **property**					
I feel confident in my ability to help manage **emerald ash borer** in my **community**					
I am able to influence management of **other invasive insects** in my **community**					
I am capable of controlling **invasive plants** in my **community**					
I know what actions to take to benefit **native species**					
I can help find solutions to **invasive species issues**					

13. Since your participation in the Wasp Watchers program, which of the following actions, if any, have you taken?

	Yes	No	Not applicable
Planted native plants on your property	○	○	○
Treated an ash tree on your property	○	○	○
Reported the presence of an invasive species in your community	○	○	○
Removed invasive plants in your community	○	○	○
Volunteered with another citizen science project	○	○	○

14. How much did participation in the Wasp Watchers program motivate you, if at all, to engage with invasive species issues?

○ Did not motivate me at all

○ Slightly motivated me

○ Somewhat motivated me

○ Significantly motivated me

Finally, a few questions about you. Your answers will help us better understand our volunteers as we continue to improve the Wasp Watchers program.

15. Which category below includes your age?

- ◯ Under 18
- ◯ 18 to 27
- ◯ 28 to 37
- ◯ 38 to 47
- ◯ 48 to 57
- ◯ 58 to 67
- ◯ 68 to 77
- ◯ 78 or older

16. What gender do you identify with?

- ◯ Male
- ◯ Female
- ◯ Prefer to self-describe ____
- ◯ Prefer not to say

17. What is the highest level of school you have completed or the highest degree you have received?

- ◯ Less than high school degree
- ◯ High school graduate (high school diploma or equivalent including GED)
- ◯ Some college but no degree
- ◯ Associate degree in college (2-year)
- ◯ Bachelor's degree in college (4-year)
- ◯ Master's degree
- ◯ Doctoral degree
- ◯ Professional degree (JD, MD)

18. Besides Wasp Watchers, how many citizen science programs, if any, have you volunteered with in the past 12 months?

- ◯ None
- ◯ 1 program
- ◯ 2 programs
- ◯ 3 or more programs

19. Have you ever worked in a science or natural-resource field?

- ◯ Yes
- ◯ No

20. What did you like the most about participating in the Wasp Watchers program?

____

21. Do you have any ideas for improving the Wasp Watchers program? If so, what are they?

____

22. Do you have any other comments?

____